NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-803

Volume II

Landsat Follow-On: A Report by the Applications Survey Groups

Discipline Discussions

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

December 15, 1976

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PREFACE

This survey was conducted by the Space Sciences Division of the Jet Propulsion Laboratory for the Office of Applications of the National Aeronautics and Space Administration.

ACKNOWLEDGEMENTS

The users who contributed to this report are listed in Appendix E of the Executive Summary volume with identification of their discipline group. Further information on each contributor is in the contributor's respective discipline part. The chairmen of the groups are from the user community and are as follows:

Mineral and Petroleum Exploration (MP): Dr. Robert Vincent
Inland Water Resources (IW): Dr. Robert Ragan
Land Inventory (LI): Mr. Charles Parrish
Agriculture (A): Dr. Ernest Hardy

The bulk of the material in this study was provided by the members on a voluntary basis. The amount of material and time invested by each member is, in itself, indicative of the concern and need for user participation in a Landsat program. The group chairmen coordinated their groups' activities, contributed as authors, organized their group study and report, and participated in a presentation of the study to NASA.

Several of the members were of invaluable help to the chairmen with these activities. They include: Ernest Lathram and William Trollinger for Mineral and Petroleum Exploration, along with the sub-group chairmen,

Ron Marrs - Mineral Resources Exploration
John Bennett - Energy Resources Exploration
Paul Merifield - Hazards, Engineering Geology
Yngvar Isachsen - Mapping and Interpretation

For Land Inventory, Bruce Rado and Lawrie Jordan (not an ASG member), along with the sub-group chairmen,

G. Robinson Barker - Forestry, Range and Wildlife
Bruce Bullamore - Natural Resource Inventory
Virginia Carter - Wetland Mapping and Inventory
A. Lawrence Grabham - Coastal Zone and Shoreline Mapping
Alden Colvocoresses - Mapping and Cartography
Charles Hoyt - Surface Mining Extent and Reclamation
Roger Zanarini - Urban and Special Environment

For Agriculture, Jack Estes, David Brueck, Richard Phelps, and Don Moore.

The coordinating members from Jet Propulsion Laboratory (JPL) are:

Mr. Fred Billingsley

Mr. Michael Helton

Mrs. Veronica O'Brien

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ABSTRACT

In January 1976, NASA requested the Jet Propulsion Laboratory (JPL) to conduct a study of the attempts at operational usage of the Landsat imagery by non-NASA users. In this study, particular emphasis was to be placed on profitable use of the imagery, as contrasted to those investigations concerned with research and development of a technology. The outcome of the study was to be an evaluation of the proposed Landsat follow-on effort as seen from the point of view of users attempting profitable use.

In support of this, four Applications Survey Groups (ASGs) were formed. These four groups so defined are:

- Mineral and Petroleum Exploration
- Inland Water Resources
- Land Inventory
- Agriculture

Other possible major interest areas such as Oceanography and Weather and Climate already have operating user groups. It was therefore decided not to try to parallel or duplicate that effort.

The task for each of the four AGCs was defined as ".....will provide to JPL for OA/NASA a formal evaluation of Landsat follow-on capabilities from the total community of users of NASA technology in its discipline area. The area of concern will be limited to Landsat follow-on activities." The specific end product was to be an evaluation of the functional capabilities of the Landsat follow-on and ground systems designs in terms of user requirements and desiderata for data measurements, products, and parameters.

The members were drawn from all segments of the user community: federal agencies, state and local governments or agencies (or from associations of such constituencies), industry and universities. They were selected so that in aggregate they would be able to adequately assess the state-of-the-art in their technical areas and represent this in the ASG deliberations.

PART 1

INTRODUCTION AND OVERVIEW

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CHAPTER I

FORMATION OF THE APPLICATIONS SURVEY GROUPS

In January, 1976 NASA requested the Jet Propulsion Laboratory (JPL)* to conduct a study of the attempts at operational usage of the Landsat** imagery by non-NASA users. In this study, particular emphasis was to be placed at profitable use of the imagery, as contrasted to those investigations concerned with research and development of a technology. The outcome of the study was to be an evaluation of the proposed Landsat follow-on effort as seen from the point of view of users attempting profitable use.

Note the term "profitable use" as contrasted with "quasi-operational use" or "operational use". This term is used to differentiate on one hand that group of people for whom the development of technology is their raison d'etre, and from that group for whom technology is a tool in the accomplishment of some other task. We have avoided the terms involving "operational" to avoid the question of "when does a quasi-operational system become operational?". The term "profitable" permits the possibility of getting real use from the data from even a quasi-operational spacecraft/ data examination system. We anticipate that those who have found the use of such data profitable will continue and expand its use, thus in a defacto way becoming operational, whether or not the formal definition has been made.

In support of this, four Applications Survey Groups (ASGs) were formed. These have been defined to have interest areas parallel to four of the NASA discipline teams, as these teams have proven to have an effective distribution of interest areas and could be used as technical resources. These four groups so defined are:

- Mineral and Petroleum Exploration
- Inland Water Resources
- Land Inventory
- Agriculture

Other possible major interest areas such as Oceanography and Weather and Climate already have operating user groups. It was therefore decided not to try to parallel or duplicate that effort.

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* Pasadena, California. JPL is operated under contract to NASA by the California Institute of Technology.

** Landsat 1, the first earth resources satellite, was launched July 23, 1972 and is still operating. Landsat 2 was launched on January 22, 1975 and is also operating. (These are discussed in more detail later.)

The task for each of the four ASGs was defined as " . . . will provide to JPL for OA/NASA a formal evaluation of Landsat follow-on capabilities from the total community of users of NASA technology in its discipline area. The area of concern will be limited to Landsat follow-on activities." The specific end product was to be an evaluation of the functional capabilities of the Landsat follow-on and ground systems designs in terms of user requirements and desiderata for data measurements, products and parameters (see Appendices B and C).

To keep the discussions within bounds the discipline areas of each group were defined to have sub-applications as listed below. These were felt to include the major interest areas of each group. However, it was left to each group to modify the list (keeping within the general framework) as it saw fit.

Mineral and Petroleum Exploration

- Mineral Resources Exploration
- Energy Resource Exploration
- Hazards/Engineering Geology; Detection, Assessment, and Monitoring
- Mapping and Interpretation; Landform, Rock Type, Structural

Inland Water Resources

- Snow Mapping and Runoff Prediction
- Lake Ice Monitoring
- Glacier Inventory
- Estuary Dynamics and Water Quality
- Subsurface Water Survey
- Water Use Survey
- Watershed Survey, Management and Modeling
- Surface Water Mapping

Land Inventory

- Natural Resources Inventory
- Coastal Zone and Shoreline Mapping and Inventory
- Wetlands Mapping and Inventory
- Surface Mining Extent and Reclamation Monitoring and Inventory
- Wildlife Habitat Location and Inventory
- Urban and Special Environmental Area Land Cover Inventory
- Mapping and Cartography
- Information Management Systems
- Forest and Range
    - Timber Inventory - Large Area
    - Range Readiness and Management
    - Forest and Range Renewable Resources Inventory
    - Wildland Protection and Damage Survey

Agriculture

- Crop Survey and Reporting (Identification, Mensuration, Location, Yield, Production, Signature Extension)
- Crop Stress (Insect Damage, Disease Damage, Crop Vigor, Soil Moisture
- Crop Management (Damaged Crop Identification, Quantification, and Location: Field Operations Information)

The groups vary in size from 13 members (Agriculture) to 46 (Land Inventory), reflecting the variation in the number of sub-application areas covered. Membership was by invitation from JPL, drawn from tentative lists provided by the Federal Interagency Decision Team, review of various lists of Landsat experimenters, participants in such activities as the Earth Resources Survey Symposium and the National Research Council study on practical applications of space systems, personal knowledge of the organizers, and recommendations from other individuals. The membership was limited to recognized experts in one or more of the fields covered by the ASGs. The members included both those who do and do not possess extensive hardware or space-related training and experience. They were drawn from all segments of the

user community: federal agencies, state and local governments or agencies (or from associations of such constituencies), industry and universities. They were selected so that in aggregate they would be able to adequately assess the state-of-the-art in their technical areas and could represent this in the ASG deliberations.

Two figures are shown herewith: (1) a map showing the geographical location of the various members, and (2) a histogram representing the members' evaluation of themselves on a scale from scientist to manager and a member classification distribution.

The survey was initiated at a combined meeting in early March 1976, at which briefings (primarily by NASA personnel) defined the spacecraft mission and some of the concepts of the data dissemination. As much back-up material as was available was distributed to the groups, both at the meeting and subsequently. Under the general direction of JPL, each group organized itself and assigned specific tasks for members to be accomplished prior to the second meeting. At the second meeting of each group the reports which had been generated to date were reviewed and the combined report begun. The first drafts of these reports were received by JPL in mid-June, and after minor editing were submitted to NASA in preliminary form on July 1, and after further polishing, in final form on August 1. This edition is the material of the August 1 report, re-edited to a more compact format.

This edition is published in the form of two volumes, a summary volume plus one covering discussions of the discipline areas. Each of the individual discipline parts begins with a summary of the state-of-the-art of the applications, followed by detailed discussions of the area. The format of the discussions follows general suggestions from JPL. Except for some chapter reorganizations for uniformity of all the discipline parts, these reports are presented in essentially unedited form. Thus the user thoughts and flavors are preserved as much as possible; the editors take any responsibility for damage done to them in the editing process.

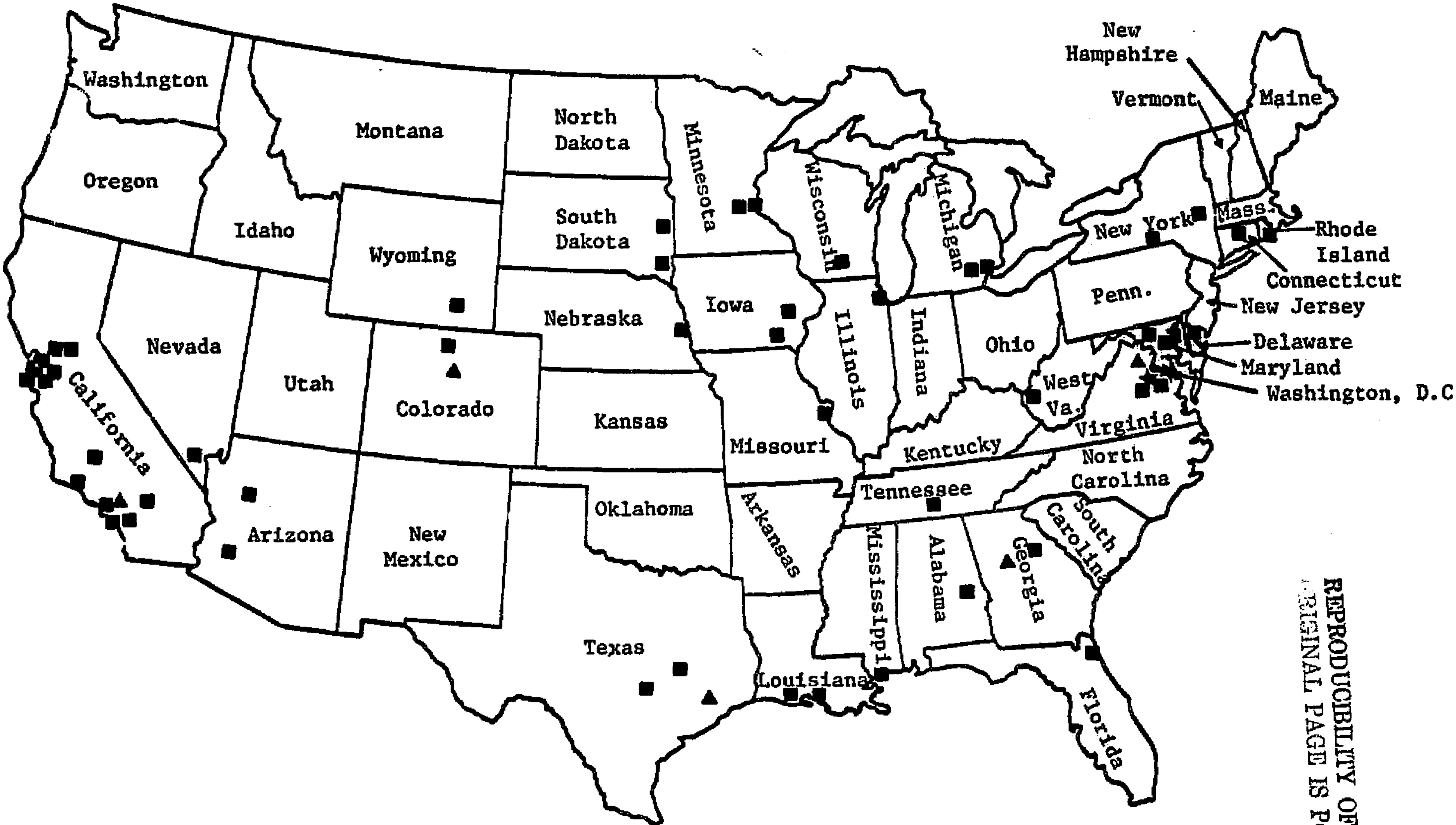
It will be found that a number of the areas of discussion are multi-faceted and therefore parallel discussions occur, both within some parts and across parts, e.g., snow and ice melt mapping is of interest to Land Inventory in their considerations of timber, range and wild land, to Inland Water in their considerations of water supply, stream runoff, and the like, to Agriculture as

a possible water source for irrigation, and to Mineral and Petroleum as it affects shipping to the Polar regions and provides demarcation of geomorphic land forms. Rather than attempt to edit out the overlap, we felt that a better picture of some of the parallel activities and overlapping considerations would be preserved if the overlap remained.

In summary, the study was designed to provide an opportunity for knowledgeable and experienced users to express their need for data which might be expected to be provided by space systems and to relate the proposed capabilities of Landsat follow-on system to these needs. Although an attempt has been made to provide a background discussion for each of the evaluations, the study does not attempt to develop these in scientific detail, nor does it provide detailed economic analysis, nor justifications for the expressed use.

FIGURE I-1

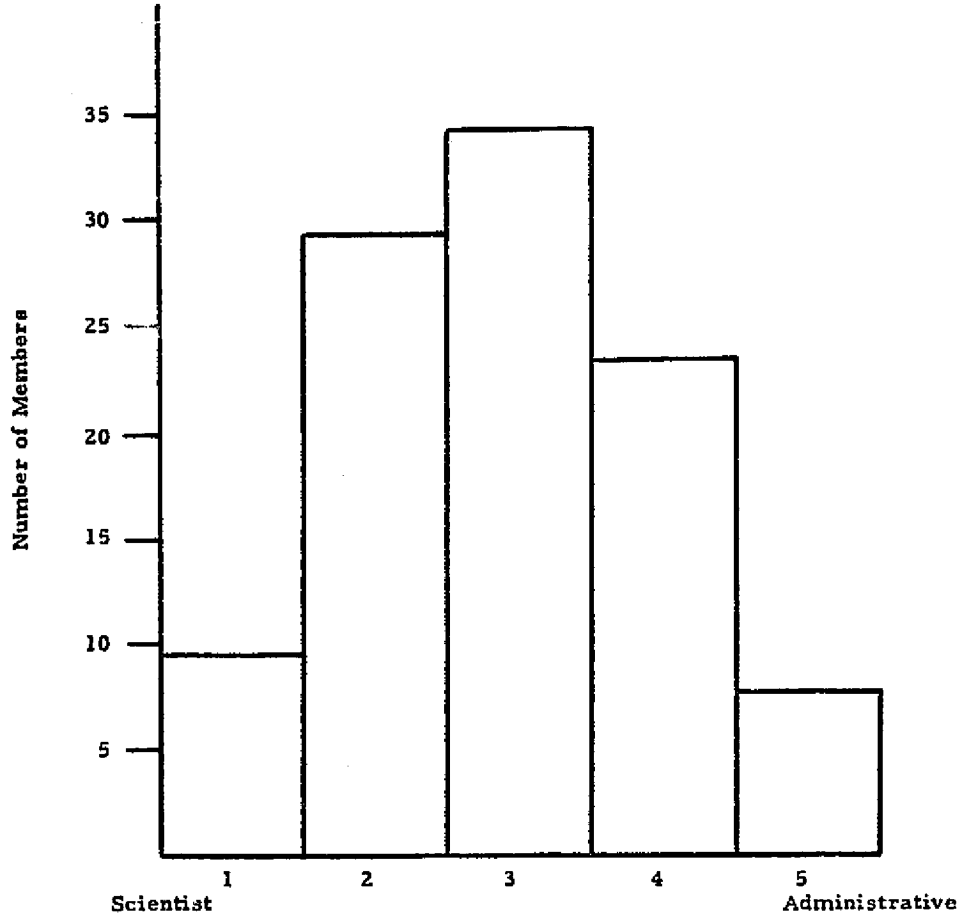
GEOGRAPHICAL LOCATION OF ASG MEMBERS



■ 1 - 3 members

▲ 4 - 6 members

★ 7 and over members



HISTOGRAM OF ASG MEMBERS

MEMBER CLASSIFICATION DISTRIBUTION

ASG	FED. WASH	FED. NON-WASH	STATE & REGIONAL	UNIVERSITY	INDUSTRY	TOTAL
MP	5	5	3	6	8	27
IW	7	7	5	5	1	25
LI	25	2	10	5	4	46
A	3	1	1	3	5	13

TABLE I-1

TABLE I-2

USER ORGANIZATIONS

FEDERAL	STATE/REGIONAL	UNIVERSITY	INDUSTRIAL
USGS/GAP, WRD, LUDA, Topo., Geol. Div., EROS	Dept. of Water Res. (Sacramento, CA) (Denver, CO)	Texas A & M	St. Regis Paper Company
NSF	Area IV Reg. Plan. (Ottuma, IA)	University of Connecticut	Exxon
CERC	Nat. Weather Serv. (Sacramento, CA)	University of California	FMC
EPA EMSL/MOW	Gt. Lake Basin Comm. (Ann Arbor, MI)	University of Virginia	Monsanto Company
NOAA/Ocean Survey, NESS, EDS, OCZM	Water Div. Board (Austin, TX)	University of California at Santa Barbara	Geoscience, Inc.
NPS/MSTL	Dept. of Conserv. (Sacramento, CA) (Nashville, TN)	California Institute of Tech./Jet Propulsion Lab.	Coastal Environments
USAC of Eng./Water Resources, NCD	State Ed. Dept. (Albany, NY)	Bureau of Econ. Geo.	Halbouty Alaska Oil
OCE	Dept. City Planning (Los Angeles, CA)	Colorado State University	Bittinger and Associates
ETL	Geo. Survey (Iowa City, IA)	Cornell University	Ralston Purina
EMA Hydro. Ctr.	Dept. of Nat. Res. (Atlanta, GA)	University of California at Berkeley	California Earth Sciences
Bureau/Mines, Census, Land Mgmt., Indian Affairs, Reclamation	Kern Cty. Water Agency (Bakersfield, CA)	University of Delaware	Cargill Grain
ERL	State Planning Agency (St. Paul, MN)	Stanford University	Anderson Clayton
USDI/Fish and Wildlife Service	Reg. Council of Govts. (Denver, CO)	San Diego State University	Chevron Oil Field
USDA/ARS/Forest Serv.	Res. Information Sys. (Phoenix, AZ)	University of Maryland	Metrics, Inc.
HUD/FIA		Auburn University	Trollinger Geological Assoc.
Dept. of Trans.		University of Georgia	Geospectra Corporation
		University of Wisconsin	Upland Industries
		University of Wyoming	
		Pennsylvania State Univ.	

The next chapter presents the results of the study in a condensed summary form with references to the individual ASG discipline discussions. Chapters III, IV, V, and VI present the key point issues in each of the four disciplines. The wording of these four chapters has been extracted from the four ASG discipline discussions so that the Executive Summary could stand by itself, thus a certain amount of repeat wordage exists between the Executive Summary and the discipline discussions.

CHAPTER II

MISSION EVOLUTION

A. EVOLUTION OF NEED FOR RESOURCE MANAGEMENT

Man has had an effect on his environment ever since he first began to deliberately cut into the ground to plant his crops. As he became more inventive, he found new ways to alter the environment and the face of the land by building cities, by cutting down forests to clear agricultural land and provide timber, by removing the extractable resources (most recently by massive strip mining), and by polluting the very air he breathes, to name a few. When the population on the earth was relatively small and the effects of man's activities were quite localized, the effect of man's presence on the earth was minute compared to the variability of nature, and in any event, healed rapidly enough to prevent a cumulative effect. Indeed, it is surprising, considering the total mass of the sea, the land and the atmosphere, and the tremendous energies involved in natural phenomena, that man has reached a stage where he can affect (and some would say destroy) his environment. There is mounting evidence, however, that this is indeed the case; alteration of life as we now know it is a distinct possibility.

Man has caused this situation through two factors: the exponentially increasing population of the earth, and his technical ability to do more and more things in a bigger and bigger way. The effects of man's activities are no longer localized to the activity itself, (e.g., in the immense downwind plumes of some smoke stacks), but may spread over extended areas, eventually with the possibility of showing up as world-wide problems. Thus there is a growing realization that the planet we call Earth is a self-contained finite milieu in which we move and act but which can and must be maintained by wise management of its food, fiber, air, mineral, and other natural resources.

Thus we are driven to see the need for managing the resources of the earth and doing so in a timely fashion so that any deleterious trends may be corrected before they become catastrophic. We are also coming to the understanding that this management must include the realization that many of the resources previously considered infinitely available may shortly reach a plateau of productivity (as in the total

amount of agricultural land available) or in actual quantity. Natural gas and oil are relatively new fuel sources in the history of man; yet the world is now drawing so extensively upon these resources that they may be virtually exhausted by the end of the 20th century. Nuclear energy has been considered the bright hope in the energy field, but supplies of fissionable uranium are short lived in relation to man's long term needs.

For ages man has been operating under the assumption that supplies were limitless, and all that was required was his ingenuity in finding the materials. The rate of exploration and exploitation, therefore, were governed by economics only. So far, he has been lucky enough to discover, or clever enough to invent the materials and goods required for his ever-increasing standard of living. Now these supplies of easily extractable raw materials seem to be dwindling, and what remains, until it is exhausted, is becoming increasingly difficult to obtain. During the days of expansion of the United States, increased food for the increasing population was obtainable by bringing more and more land under cultivation. In this country, however, we have now reached a turn-over point caused by the fact that arable land is being removed from cultivation (e.g., by urbanization) more rapidly than new land is farmed. In addition, 8.4 million acres of commercial timberlands were diverted to agriculture, inter-state highways, airports, urban areas, parks and smiliar uses in the 20 years between 1950 and 1970.

These competing uses for a non-growing resource have long-term implications which must be studied to assure that the trade-offs involved are understood. More and more, the public is becoming aware of the finiteness of the resources, resulting in an ever increasing amount of legislation at all governmental levels concerning monitoring and controlling extraction of non-renewable resources, usage of renewable resources, activities which affect the environment, and the like.

B. EVOLUTION OF THE NEED FOR MANAGEMENT DATA

Thus we are coming to understand that the raw materials available to us are not infinite, that the energy required to extract them and modify them for our use also is not infinite, and that more and more we are affecting our environment by our very quantity and ever-increasing activities. The new laws being passed require that we

become more effective in the management of these resources. Our historic approach has been to increase the rate of discovery to satisfy the increasing demands. As long as this can be continued, it will defer the day at which exhaustion of a particular resource does occur. In addition, we are now being driven to attempt to conserve what we have by making existing goods last longer and to recycle materials, the latter also resulting in an energy saving by the avoidance of processing of new raw materials.

These and similar related activities are placing upon us an ever increasing demand for better management data. In the context of this discussion, this means more and better data concerning exploration (new cross faults have been discovered in Nevada which appear promising as locations of mineralized areas), for optimum utilization (the synoptic view afforded by Landsat has enabled planners to do their tasks more efficiently) to detect pollutants in the air and water, and to monitor some agricultural processes. It is indeed fortunate that along with the evolution of the need for resource management, man is evolving the technology that will allow him to gather the data required to do that management.

With the increasing pace of activities and the ever increasing effects of these activities, new and more efficient methods of obtaining the data are continually required. In addition, as man's tasks become more complex, more data types may be required simultaneously to solve the increasingly complex problems. To use a familiar example, the addition of the near infrared spectral band to color conventional photography now allows farmers to detect certain types of stress (using the false color infrared film so produced) before it becomes visible to the eye. The addition of even more spectral bands to the Landsat satellite has allowed the detection of certain hydrothermally altered zones, indicative of mineralization, from satellite altitudes.

The synoptic view obtainable from satellite altitudes has eliminated the need of much tedious mosaicking formerly required when using aircraft photographs, and the ability to use spectral bands not available through photography has allowed the detection and mapping of some phenomena not observable in other ways. The detection of mineralization from satellites as mentioned above has minimized the need of extensive

aircraft or foot surveys. In addition, the synoptic view has provided visibility of large scale effects which had previously been undetected.

The ever growing need to understand the changes occurring in the environment in a timely fashion has led to the need for viewing the same areas repeatedly. This type of data has been available haphazardly, to date, through the disinterring of old photography, with all of the vagaries implicit in attempting to use data of widely divergent types. The availability of satellite data has opened a new vista by providing synoptic repeat imagery taken under constant conditions. The data thus now becoming available, of both the anniversary (year-to-year) and non-anniversary (season-to-season) types are beginning to provide the data base necessary to monitor and eventually understand the dynamics of spaceship earth. In addition, the need to monitor, understand and react to short-lived phenomena such as floods will be met by this same data, provided that suitable rapid data delivery systems are provided.

Man's efforts at becoming more and more efficient in the use of the natural resources has generally tended toward massive systems, as witness the strip mining of areas equivalent to entire states or the extensive mono-culture resulting from the extensive use of optimum strains of corn with the attendant possibility of "wild fire" spread of corn blight. The wide spreading situations which man thus finds he must monitor, understand, and eventually control are indeed calling for data of more precision, of more variety (for example, spectral bands beyond the range of film photography), and of the form (for example, digital) allowing the subtle analysis required to extract the required information.

Thus it is seen that the satellite data, particularly imagery, although it will not replace aircraft photography, can and is beginning to provide the data needed by man in understanding his milieu, and in evaluating the effects of his activities. These extra capabilities are not available to him, however, without a price. That price is the complexities involved in the increasingly more subtle analysis required. It has typically been true in our culture that today's luxuries are tomorrow's necessities. In this context the monitoring analysis and eventual management of our resources, which are viewed by

some as luxuries today, will be found to be vitally necessary to the maintenance of a reasonable standard of living. Increasingly, this calls for data interpretation far beyond the old photointerpreter approach in order to reap the benefits available from the more exotic data. Analysis technology will need to be further developed and training must be provided at all levels to avoid producing a technology gap between the advanced technologists and the ultimate users.

C. EVOLUTION OF THE TECHNOLOGY

Prior to the advent of photography, all knowledge of the environment had been obtained through what we might call proximate sensing, that is, by being directly in proximity to the object being viewed. The dissemination of information about this object had to be through a description of it, simple or elaborate as the case might be, augmented by drawings where appropriate. The recipient of this information was at the mercy of the describer, and error or ineptitude in the description could lead the recipient completely astray. He had no access to the original information from which to draw his own conclusions or on which to make his own observations.

In the earlier days of resource management, the local farmer or manager could derive all the information he needed by proximate sensing. As the new tool called photography became available, it provided the possibility of making a record which could be subsequently analyzed. The availability of photographs does not remove the need for proximate sensing, but rather utilizes it for verification and interpretation and for calibration.

The advantage of the photographic record was immediately apparent. In 1840, Arago, director of the Paris Observatory, referred to the Daguerreotype process and advocated the use of photography for topographic purposes. In 1858 balloon borne photographs of Paris were made by Laussedat, who subsequently derived the required mathematics for converting them to orthophotographic projections. The use of balloons, kites, and eventually airplanes, was a natural progression for the carrying of photographic equipment. The earliest uses of photography for use in mapping was first described at the International Society of Photogrammetry meeting in 1913. Soon after this, the importance of aerial photographic reconnaissance was recognized, and cameras

developed especially for aerial reconnaissance were available by 1915. Development of photointerpretation techniques has continued to this day as an integral part of military operations.

As early as 1853, an official photographer joined an exploration expedition, one in which Col. John Fremont sought a more direct route to California across the Rocky Mountains. The growing recognition of photography during these early western surveys led to the development in 1890 of the Committee on Photographs of the Geological Society of America. The first use of cameras for topographic surveys resulted in the publishing of a book in 1895 on photographic mapping. Aerial photography was utilized about 1920 by petroleum geologists.

However, it was not until about the 1930s that aerial photography came to be used for interpretive uses, as contrasted to photogrammetric uses. This has resulted in a number of comprehensive volumes on interpretation of photography, culminating in the Manual of Color Aerial Photography in 1968.

It is obvious that photography removes one of the critical limitations of the resource manager, namely, the need to be there himself. Instead, it provides him with the opportunity of subsequent analysis, as well as providing him with permanent records. In addition, and just as important, the photographs can be duplicated and disseminated so that numerous photointerpreters may each glean from the photographs what they will. Thus, there is no need to be restricted to the interpretations produced by the first photointerpreter to analyze an image.

The first widely available color film was Kodachrome, introduced in 1935. Interpretation and the value of color photography for earth science purposes was discussed as early as 1941 by A. J. Erdley, but it was not until 1952 that serious discussions of the value of color aerial photography for geologic purposes were held.

Incorporation of an infrared sensitive layer in the color film occurred in 1942, upon request of the military for camouflage detection film. Although originally developed as a military reconnaissance tool, it found extensive use in the plant sciences. As early as 1956, Colwell performed some of the early experiments on the use of special-purpose photography for detecting plant stress.

In spite of the widespread utility of color infrared (CIR) film, it must be recognized that it is a broad-band film and is therefore not optimum for detecting effects which occur in relatively narrow spectral zones. Although the use of spectra-zonal film was proposed as early as 1942 by S. Q. Duntley, spectra-zonal photography has primarily found application via black-and-white film and narrow band color filters. This allows control by the user of the spectral bands desired so that a given photographic experiment can be tailored. In addition, it has generally been true that the chemical processing of black-and-white film can be accomplished with greater precision than the processing of color film, so that numerical measurements made from such photography begin to be meaningful. This technique has resulted in the development of a number of multi-lens cameras and multi-camera arrays. Multi-lens cameras and related color additive viewers are now commercially available.

Experiments with spectra-zonal photography resulted in the S-065 experiment in which an array of four Hasselblad cameras was used, three with black-and-white film and color filters, and the fourth with CIR film. The system was assembled to simulate the then proposed ERTS -1 spacecraft and flown on Apollo 9. The efficacy of this type of photography being proven, the first ERTS satellite was launched on July 23, 1972 (it is still working as of June, 1976) and by Landsat 2 on January 22, 1975 (these have subsequently been renamed Landsat 1 and 2). The general characteristics of this spacecraft are as follows:

Each Landsat was launched into a near polar orbit at an altitude of 910 km (547nmi). It circles the Earth 14 times a day, acquiring images of about 168 scenes per day. The multispectral scanner (MSS) returns images in four spectral bands (green, 0.5 to 0.6μm; red, 0.6 to 0.7μm, near-infrared 1, 0.7 to 0.8μm; and near-infrared 2, 0.8 to 1.1μm). Instantaneous field of view is 57 x 79 meters. Each image is approximately 185km (100nmi) square. On a picture element (pixel) scale, each scene element is roughly equivalent to 1.18 acres.

At the equator, the centers of successive strips are spaced 2800 km apart, so that 14 such strips may be observed around the world every day. The orbit is adjusted so that a strip observed on one given day, in one given location, advances westward by about 170km on the next

day. In this fashion, the spacecraft sensors view the entire Earth between 83 deg N and 83 deg S once every 18 days. Landsats 1 and 2 are phased to give interleaved coverage every 9 days. However, limited power, data transmission and, above all, data-processing capability prevent acquisition of images over the entire Earth during every 18 day period. Thus, contiguous images are acquired every 18 days only over the North American continent. For the rest of the Earth, selected strips over portions of the orbit track are imaged. Every day, these strips amount to about 26,000 km in length and 185 km in width. They are chosen on the basis of cloud cover forecasts and requirements of NASA-approved investigators.

During the daytime, the satellite passes from 81 deg N to 81 deg S in a south-southwesterly direction. Images are acquired during this SW-trending portion of the orbit. During nighttime, the satellite transmits the measurements recorded over other parts of the Earth to three U.S. stations.

Data from the MSS are distributed in the form of film images or machine readable digitized data on magnetic tape. Copies of the Landsat data and photos, after being processed at Goddard Space Flight Center, are forwarded to the Department of the Interior's Earth Resources Observation Systems (EROS) Data Center at Sioux Falls, South Dakota, for distribution to the public.

With the success of Landsat, the potential of a timely and accurate inventory of the current use of the Nation's land resources now exists. In 1971, an Interagency Steering Committee on Land Use Information and Classification was formed, with members from the USGS, NASA, Soil Conservation Service, International Geographical Union, and the Association of American Geographers. The eventual outcome resulting from the activities of this committee was the publication of the USGS Circular 671, a classification system which takes advantage of remotely sensed data, and which has found wide acceptance. As more experience with remote sensing was gained since that time, this system has been revised and published in 1976 as USGS Professional Paper 964.

Spurred by the success of Landsat, the American Society of Photogrammetry published the Manual of Remote Sensing in 1975.

With the dramatic success of numerous experiments utilizing the Landsat 1 and 2 data, Landsat C is now scheduled to be flown in September, 1977. It will be the same as Landsats 1 and 2, with the addition of a thermal infrared channel of lower spatial resolution covering the band of approximately 10.5 - 12.5μm. This will provide the first opportunity for experimenting with thermal data from orbital altitudes in conjunction with the reflective data of the other channels. It is the data from Landsat 1 and 2 that form the basis for most of the discussion in the remainder of this report.

The extensive experience with the data from Landsat 1 and 2 has indicated the desirability of modification of some of the parameters. As a result, the multi-spectral scanner of a proposed Landsat follow-on (the Thematic Mapper) is currently proposed to produce data of the following characteristics:

Spectral Bands: 0.45 - 0.52μm, 0.52 - 0.6μm,
0.63 - 0.69μm, 0.76 - 0.90μm,
1.55 - 1.75μm, 10.4 - 12.5μm.

Instantaneous field of view if orbit is 705 km:
30 m (Reflective)
120 m (Thermal)

Image Size: 185 km x 185 km

One picture element is about 0.3 acres.

Two spacecraft phased to give 9-day repeat coverage.

Payload will also include an MSS of the present design.

The following two pictures of the Washington, D. C. area are from a Skylab photograph which was digitally scanned to simulate a monochromatic photo with resolutions of 80 meters (top) and 30 meters (bottom). This demonstrates the difference between present Landsat images (top) and the Landsat follow-on images (bottom). The scale is 1:125,000.

The various contributors to this report have attempted to evaluate the utility of the new parameters in light of their own experience.

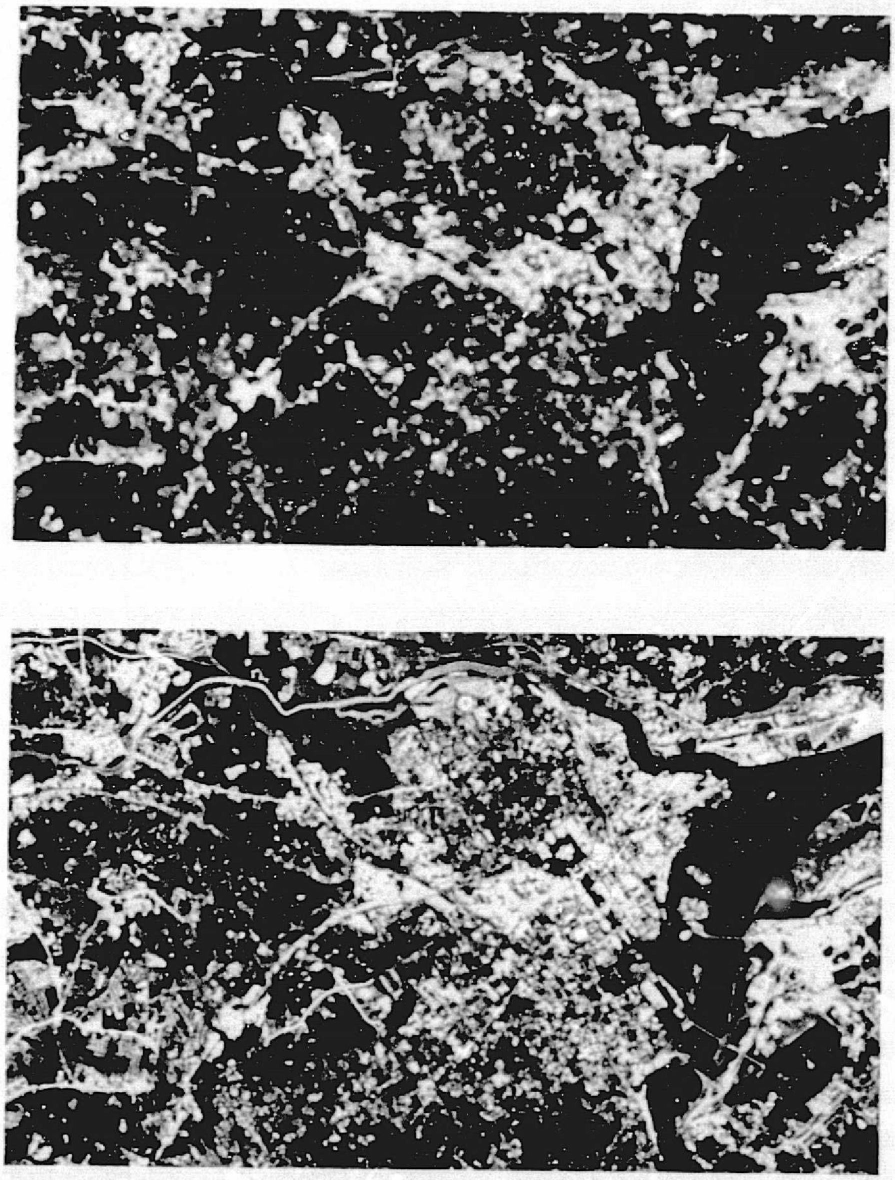


Figure II-1. Washington, D. C. area digitally scanned to simulate a monochromatic photo with resolutions of 80 meters (top) and 30 meters (bottom). The scale is 1:125,000.

D. CONCLUSIONS

We have traced the evolution of the need for management of our natural resources, the evolution of the need for more data, and in a more timely manner, to do this management, and the evolution of the remote sensing technology from proximate sensing to satellite imagers. These three evolutions have taken place more or less in parallel. The major step forward in the use of photography for resource management has been fairly thoroughly exploited. The photointerpretive techniques developed have provided resource managers with a new tool which has allowed them to develop techniques and models previously unworkable. The availability of satellite data now provides them the repeat coverage and synoptic view necessary to carry their management a step further, and this in turn is beginning to call for satellite data with improved parameters.

Historically, the time lag between inspiration and utilization has been shortening. The computer has evolved from work carried out some 40 years before on basic solid state physics. The laser has evolved from work performed 30 years earlier. Although Landsat has been with us only since 1972, experimenters around the globe have taken advantage of the synoptic repeated views available to them, using spectral bands which were hitherto unavailable. Already this data is being incorporated as an important data source.

Now, with the promise of Landsat follow-on and its improved parameters, even further applications seem possible. The remainder of this report outlines the state-of-the-art as seen by recipients of the data, who outline some of their expectations of use of the improved data to come.

We must emphasize that the use of this improved data will not be automatic. Remote sensing is rapidly becoming more complex, but increased complexity does not necessarily produce increased worth. Without suitable training of potential users, a lack of technology acceptance by them may mean that as a technique becomes more complex, it will become less used at the same time that the task of the resources manager is becoming more complex in itself, due to the increased finesse required in utilizing those resources. Wise management will be greatly facilitated if timely, accurate inventories are periodically made available to him. It seems true that almost invariably these better inventories can be made by remote sensing of some sort.

The complete process of supplying the resource manager with the information he can use thus must include not only the data acquisition phases but adequate and timely dissemination of the data in a form usable by the resource manager, and a mutual program in which the resource manager educates the data technologist to his need, and the data technologist educates the resource manager as to the state-of-the-art of data acquisition and analysis.

CHAPTER III

APPLICATIONS OVERVIEW

A. THE REMOTE SENSING PROBLEM

1. General

Data collection activity, wherever it is done and regardless of its sophistication, involves three distinct operations:

- physical data acquisition
- basic data reduction to usable form
- dissemination of results to the users for their use in decision making.

As sophistication increases, there is a predictable exponential increase in data such that reduction and dissemination may well become the limiting factors within the system.

With the advent of satellite systems as viable sources of earth's resource data, a near epitome of automated data acquisition has been reached in which the data reduction and dissemination aspects have become monumental, far transcending anything envisioned only a decade ago.

In surveying applications of remotely sensed satellite acquired data, all three parts of the system must be evaluated. Data acquisition, reduction and dissemination must all be achieved to even claim a system. To these three, conceptual methodology development must be included if such a system is to be dynamic and responsive to advanced knowledge and technology.

a. Data Acquisition

Data acquisition includes the data collection and delivery for processing. This includes the data, its quantity and quality, the instrumentation of collection in precision and options available and the mechanisms of transfer for reduction, in terms of data handling efficiency and speed of turn around.

b. Data Reduction

Data reduction activity takes place after the required data are retrieved and subjected to secondary processing to render results with utility to the potential user. This would include both the philosophy of classification; i.e., pattern recognition through clustering or modified clustering, algorithms, etc. and the hardware/software configurations to accomplish the task.

c. Data Dissemination

Once the data are reduced to usable form, how is it to be transferred to the user and how does the user interface with the system?

d. Conceptual Data Collection Systems

What should we be aiming for in the future data collection systems? Such a question must be addressed in light of what we already know.

First of all, what are the basic objectives of the system? To what degree does the current capability meet these objectives? Should the system rely on the satellite and its instrument as a stand alone source, or as just one of many data gathering tools which together provide an integrated system?

e. State-of-the-Art

The Earth's Resource Program as envisioned by NASA has as basic objectives the following:

- Develop capability for remote sensing from spacecraft and aircraft.
- Develop experimental and operational applications of ERS technology to meet user requirements, and transfer to the users.
- Develop methods of handling and processing large quantities of remote sensing data.

Given these objectives and tasks expectations from NASA, it can be truly said that the state of the art has but just scratched the surface. This statement is true even with the broadest interpretation of such terms as management, stratification, and inventory.

Aircraft data are included in the set of sensors to achieve these objectives; this report will assume that satellite data is not to be considered as an end unto itself but as an added dimension to an already established technology.

In general, projects completed or in progress indicate most of the stated objective are obtainable, at least in a very broad basis, perhaps to a level II or III precision. Of course, accuracy suffers with each level of precision. Presumably, when the system's accuracy becomes marginal, a sub-system will be interfaced, with the process being repeated until the level of desired precision is reached. Establishing these interface points is rather critical, with the efficiency of the entire system being at stake

Although very few, if any, projects have been developed in an operational atmosphere, that is to say, implementable by a user on a day-to-day basis, results strongly suggest a significant contribution by Landsat to overall resource data systems.

The following report will review a representative selection of tasks done or being done utilizing Landsat 1 and 2 data. This review will attempt to establish the value of an operational satellite system as a viable data source in achieving NASA goals. The assessment will be made in light of current hardware configuration and data handling procedures, and will try to evaluate the input of extended capabilities as envisioned in Landsat follow-on.

2. Data Acquisition

Mechanisms for data acquisition are the same for all applications. The data collection vehicle is primarily a satellite, with various aircraft sub-systems being employed as needed for more precise data.

The basic sensor system built into Landsat 1 and 2 which will be considered here is the multi-spectral scanner (MSS). The smallest ground area discernible is about 1.2 acres, in each of four spectral bands.

Coverage of any spot on the ground is accomplished once every 18 days for each of the Landsat vehicles. Because of the staggered timing, however, each spot in the earth is covered once in 9 days. Since most data to date have been used in research (one time) activity, periodicity of coverage has not been a critical factor in many of the applications. For operational considerations, however, this repeatability of coverage becomes critical.

As data are received by the data collection stations, they are forwarded to Goddard Space Flight Center. Grey scale, 70 mm film products for all four bands are generated by Goddard. These products are forwarded to the EROS Data Center in Sioux Falls, South Dakota. Computer compatible tapes (CCT's) are also available by request.

The data corrections made by NASA for the film products are radiometric and geometric in nature and are done at Goddard. The data are in two forms; film mode for photo interpretation or display, and digital CCT's. The range of digital data include 128 levels of grey in channels of 4, 5, and

6, and 64 levels of grey scale in channel 7. Because of the only 10 percent sidelap, stereo capability is minimal for any detailed photo interpretive effort. To date, the most serious work done or contemplated has been based around digital data analysis. It is this form of the data that will be addressed in this report.

Because CCT's must be requested through the EROS Data Center, and considering the mass of data and orders that accumulate, receipt of data sometimes lags three months or longer behind the time actually collected. Again, as with periodicity of coverage, so long as uses of the data are primarily to develop a technology, this problem is not restrictive; however, when considered in light of an implementable operational system, this unfavorable turn-around time could become fatal to the system, especially in activities considering rapidly changing phenomena.

3. Data Reduction and Dissemination

In the following discussion on data reduction as designed for various applications the basic data in terms of periodicity, precision, range and handling must be kept in mind. Regardless of the sophistication of the various computer software packages and interpretive logic, information output can be no more precise or accurate than the data input. Extrapolation of information beyond the data capabilities can be misleading, at best, and disastrous at worst.

Data reduction activity in terms of products generated can take many forms. There are, however, some baseline activities and procedures that are universal to all computer-aided MSS digital data analysis. The ability to geometrically correct and register existing and sequential images and the ability to utilize multi-stage sampling designs with satellite data representing the generalized first stage are two very critical capabilities in rendering satellite data operational within the private sector. Furthermore, the finesse of data required by the private sector in their decision-making process is great when the sophistication of the models now being used is considered. It would seem, for now and the immediate future, that the man on the ground will not be replaced; however, it is incumbent on management to make his use the most efficient possible. Data collection systems utilizing satellite data will contribute toward this end.

a. Geometric Registration

Geometric registration is the capability to locate given ground points on remotely sensed images and to accurately superimpose these points from repeated coverage. Without this ability, remote sensing analysis techniques may become academic. Most land cover patterns are non-contiguous in nature with land cover types intermingled, and ownership boundaries and operational interest areas (for example, census tracts) form overlapping patterns of sub-compartmentalization which must be interrelated. The first stage in the required processing for geometric registration has been to correct for the various distortions in the data.

Upon receipt of the CCT's from the EROS Data Center, the tapes must be reformatted to be compatible with the local system, and then geometrically corrected. This correction involves correcting for the skew caused by the earth rotation, the slight non-linearity of the line-by-line scan, for the projection of the spherical earth onto the flat image plane, and knowledge of the image tilt caused by the orbit track. The hardware requirement for this stage of reduction is considerable. As of this writing, the centers capable of achieving this are large, few and far between locations. This fact has obvious operational implications, and although the situation is improving, will remain a serious deterrent for widespread functional implementation for some time to come. For this reason, it is suggested that these processes are valid preprocessing steps which might be performed as part of the Landsat project.

The multi-stage features of any system are not really a data reduction problem, at least insofar as the satellite data are concerned; however, the format of results from satellite data must be compatible with the results from other data sources so all the data can be utilized. To handle the registration and geographic location, digitized referencing techniques utilizing line segment or polygonal procedures have been utilized. Now, with the availability of satellite data, recently developed grid cell-based systems using raster grid cells in the 1 acre size range and overlay techniques for analysis (such as the MILUS/IBIS system) are now providing adequate interface of the satellite, aircraft, and other demarcation data to each other.

b. Stratification and Multispectral Classification

Many of the applications for utilizing Landsat data have involved stratification in one form or another, and the monitoring of change. This is measuring the difference in mapped strata on successive imagery. Stratification has been done in terms of vegetative typing, delineating areas of

cultural activity, water surface, and other types of surface cover. Because of the nature of the input data as generated by Landsat, only the broadest of stratifications are possible within any sort of statistically acceptable performance capability, using Landsat data alone. Thus, Landsat falls short of a stand alone system in achieving many of the NASA goals as stated. To achieve these goals, sub-systems of increasing precision may be interfaced, often down to the ground level, to augment the satellite acquired data. Such systems involve geometric registration and multi-stage sampling procedures that will allow for a logical progression of data collection to the level of precision required by the information system being served.

These sub-systems have not been uniquely developed to augment satellite data, but were developed as integral parts of prior data collection activity; in fact, multi-stage sampling has been a viable tool in resource sampling procedures from the beginning of modern resource management. While the sub-systems have no bearing on the satellite data collection capability per se', they do represent interfacing vehicles by which satellite data can be effectively interfaced with on-going activity. The satellite provides the broad level information source, with its large area of coverage and its repeatability, that, when added to existing techniques, will provide the data base necessary to e tively and efficiently manage our resources in the future.

The stratification process itself as seen in multispectral analysis utilizes pattern recognition logic to analyze the data on a multispectral signature basis. Utilizing these techniques requires substantial man-machine interaction throughout the process. For this reason, analysis procedures are generally referred to as computer-aided analysis techniques.

Basically, pattern recognition involves classification of the Landsat digital scenes (some 8.5 million acres) into categories of interest. Thus, instead of some 128 separate gray scale levels, some 4-20 or so classes will be identified to which each of the digital samples will be assigned.

c. Data Distribution

The bottom line of any data acquisition system is the use of the results by operational and executive management.

Assuming that the proper products have been produced (as discussed above -- geometrically corrected, films or digital tape, etc.), the next most critical factor is the delay time for dissemination.

From the earliest beginnings of the Landsat (formerly ERTS) program, efficient distribution of data to all users has been a firm program objective. The cooperative program with the EROS Data Center (EDC) was established for just this purpose. In the early stages of the program, however, must frustration was caused by start-up and other problems. These unavoidable problems are apparently still causing many potential users to hesitate before making a significant commitment to operational use of the data.

If data delivery time is longer than the tolerable delay time for a given application, the affected user will effectively be denied access to the Landsat system. This serious problem has not gone unnoticed, and substantial improvements in data delivery are planned for inauguration at about the time Landsat C is launched. Because of its importance, this is discussed in greater detail in other sections of this report.

4. Conceptual Methodology Development

Looking to the 1980's and Landsat follow-on, several new features in addition to the ones in Landsat 1 and 2 are envisioned. Each of these features will be discussed with implications of the data generated from such a hardware package.

a. Hardware

(1) MSS. The maintenance of a multi-spectral scanner as specified for Landsat C will be valuable in maintaining continuity for systems designed around that system.

(2) Thematic Mapper (TM). Really a second generation MSS, the TM holds promise for future data use from satellite sources.

(a) Resolution. For bands 1-5, a 30 meter resolution will be significant in most applications. More precise boundary locations and thus, more accurate acreage determination will be possible. Higher accuracy of classification, especially in sub-classifications, level III and smaller, may allow in some applications one or more stages of a multi-stage system to be deleted. This would be a substantial benefit/cost improvement, and would provide a more efficient system.

(b) Quantification Levels - 256

This particular feature, along with increased resolution should enhance classification capability by providing more accurate discrimination capability. While each resolution element will be an average radiation value, as it is now, the range of the averages will be reduced, providing for higher statistical classification results and broadening the range of features classifiable through pattern recognition techniques.

b. Baseline

(1) Altitude 705 km

This feature will affect both the TM and MSS. The impacts of lower altitude while maintaining the resolution on the MSS is somewhat conjectural at this point. It will mean a non-compatible scale with existing data, until suitable geometric corrections are applied. Establishing the altitude to be compatible with the shuttle seems to make good sense.

(2) Two Satellites - 9 Day Coverage

There is possible problem of cloud coverage, especially in the subtropics where convection buildup becomes a real problem. Nine day coverage should provide enough cloud free scenes to allow Landsat follow-on to be useful as a monitoring device.

(3) On-Board Considerations

The abandoning of on-board intermediate tape storage stages in favor of a domestic satellite relay system seems to sidestep the worst of

the current data handling problems. The capability of turning the data around and providing the user with current applicable data is the key to a truly operational system.

B. MINERAL AND PETROLEUM EXPLORATION AND ENGINEERING GEOLOGY

1. General

The demand for mineral raw materials to sustain the industries of the United States and other industrialized nations has increased tremendously since the beginning of this century. In most readily accessible parts of the world, unexploited easily discovered surface or near-surface ore deposits are now rare or non-existent, and concealed deposits must be sought. Any techniques that provide any kind of regional geologic information can add to the understanding of the origin and distribution of ore deposits and, hence, are useful in their exploration.

A relatively new and inexpensive technique, remote sensing, shows promise in identifying areas favorable for the location of mineral deposits and in ruling out areas of little promise, thus enabling a more selective use of costly ground exploration. Specifically, the synoptic view from remote sensors in space permits delineation of distinctive geologic features of many kinds known to be associated with various types of mineral deposits. Examples of such features are faults, folds, distinctive rock belts, ground altered by mineralizing solutions, topographic characteristics and vegetation habit.

Before the information can be used effectively for exploration, the relationship with a "target" -- an ore deposit, oil field, concentration of construction materials, or other extractable resources -- must be established. All degrees of relationships can exist.

The need for these data is made even more critical by the fact that our mineral resources are <u>non-renewable</u> and a complete and immediate inventor of such resources is critical to their proper management.

The importance of geologic mapping and interpretation for mineral and petroleum exploration and hazards/engineering geology cannot be over-stated. The geologic map provides the data base from which fundamental interpretations are made to reconstruct the chronology of geologic events affecting a region. Then, and only then, can a comprehensive and efficient exploration program (or hazards assessment) be effectively carried out.

2. Materials and Composition

The most promising techniques for acquiring information about the chemical and mineralogical composition of surface materials from satellite-borne instruments to date are based on measurements of the visible and near-infrared spectral reflectance. It is now clear that processing the MSS spectral radiance data permits subtle distinctions among rock and soil units that cannot be achieved through analysis of unenhanced images or color photographs.

Essentially, from a practical exploration point of view, the problem is to discriminate between the target and the background when there is little or no visually perceptible spectral difference reflecting subtle chemical changes in rock or soil. Even when such differences are perceptible, the physiological and psychological aspects of color viewing demand that the final representation of the colors in the output product be in objective and reproducible mathematical terms. Because the Landsat MSS is particularly sensitive to spectral variations, when a first order haze correction is made, subtle differences normally not perceptible in standard photographic products are distinguishable.

Many of the important mineral deposits of the world are associated with intrusive igneous bodies. Of great importance are porphyry copper deposits within igneous bodies of intermediate to felsic composition and in the enclosing rocks. Commonly found peripheral to these are deposits of base and precious metals. Where igneous bodies intrude carbonate rocks, deposits of tungsten, silver, and base metals may form within the surrounding zone of metamorphism.

Using presently available Landsat images it is commonly possible to delineate igneous intrusives. This involves conventional interpretive techniques based on such features as differences in rock structure, weathering, and selectivity of vegetation growth. Discrimination of rock types or alteration associated with mineralization can be made on the basis of spectral information properly combined and enhanced. Study of satellite images thus provides a basis for identifying promising exploration areas in which necessary field data can then be acquired to confirm or deny mineral potential.

3. Geologic Mapping

The geometry of earth materials is as important as their composition in mineral and petroleum exploration (e.g., oil in anticlines, sedimentary wedges, fault traps, folded sedimentary basins; ore in fault zones, around or disseminated through linear dikes or circular igneous intrusions, and along lithologic contacts; geomorphic forms for identification of construction materials). Landsat has provided capability for more regional geometric analysis as well as recognition of more indicators of geometry than previously possible.

Geometric mapping is required at levels of detail directly related to detail of exploration, i.e., very detailed mapping for selection of drill or mine sites, more general to select areas for seismic work and sampling, regional to identify petroleum provinces or mineral-rich areas, continental for assessing potential for rich areas and development of theories of petroleum potential or metallogeny.

One of the most basic types of remotely sensed information of use in minerals exploration is a sense of the geologic trends or "grain" of a new area. In regions which have been subject to considerable tectonic deformation, erosion-resistant stratigraphic units provide a pattern which may be too subtle to be apparent on topographic maps, aerial photographs, or most satellite images. These patterns are often readily discernible, however, on present Landsat images at very low sun angles, even in heavily forested terrain (SE-USA). Mineral deposits localized by particular strata can thus be traced over very large areas, and ground sampling programs planned. Regional folding patterns can be determined, and mineralization of the type that occurs in the axial areas of large, tight folds can be located. Discordant intrusive bodies, and their associated mineralization, can be detected by their interruption of strike belts.

Depositional features of economic potential include glacial deposits, alluvial fans, stream terraces, playa lakes, and deltas. These are features where economic deposits of precious metals and/or nonmetallic minerals may be concentrated by primary deposition or secondary enrichment.

Erosional features are important in mineral exploration because they provide evidence as to surface condition, recent morphologic history, and

mechanism of possible redistribution of material. One of the most important aspects of erosional morphology is the tendency for stream valleys or other surface discontinuities to form along zones of weakness in the earth's crust. These same zones also may have served as conduits for groundwater or hydrothermal fluids, or they can be critical components of geologic structure. In either case, they may be used as exploration guides.

Structural mapping includes the delineation and analysis of all visible folds (anticlines, synclines, monoclines, structural terraces, etc.) and fractures (faults of all types, joints, etc.) revealed on the imagery. Most of the structural information derived from Landsat to date has been in the form of "linears" as well as curvilinear and arcuate features. These phenomena have been strikingly discernible on the Landsat imagery. The three-fold increase in spatial resolution proposed for Landsat follow-on will provide at least two additional new contributions to the mapping of linear features: (1) the detectability of shorter linears, which, in the extensive plateau areas of the globe can be expected to provide maps of joint systems; (2) a look at the "fine structure" of large scale lineaments which may be already mapped, but which have very complex surface expressions involving numerous smaller structures. This applies particularly to the lineaments of continental dimensions, may of which are known to be deep crustal avenues of recurrent movement and mineralization.

4. Engineering Geology

Remote sensing, and in particuiar, Landsat data are useful in the selection and evaluation of sites for engineered structures in terms of geologic hazards, earth materials for engineering usage and environmental impact (exclusive of mineral and mineral fuel extraction). Remote sensing data are routinely used in site investigations for dams, power plants, flood control structures, towns, airfields, bridges, tunnel locations and high-rise buildings. These data are also applied to corridor surveys for highways, railways, canals, pipelines and powerlines, as well as in exploration for stone and aggregate and fill material.

The general factors considered during the planning stages of civil works types projects include, (1) a regional analysis of national and cultural resources to develop the scope of the project, (2) the preliminary siting of project components, (3) the development of an environmental impact statement and (4) the generation of a preliminary design for the development

of economic and other benefits, and costs of the project.

The imagery of the project region available from Landsat follow-on will provide a synoptic view depicting conditions existing at a given time and indicating relationships between climate, geology, and cultural and environmental factors that are of particular value in evaluating the impact of a new engineering facility, and also will provide a method for noting changes occurring by comparison of sequential images.

5. <u>Arctic Sea Ice Monitoring</u>

In the last ten years significant new resources of oil and gas, and of minerals, have been discovered in the North American Arctic. In 1972, estimates of new reserves of oil ranged from 50 to 200 billion barrels and of gas from 200 to 1000 trillion cubic feet. In addition, the Canadian government estimated mineral reserves at 221 million tons in the Arctic Islands. With exhaustion of reserves and social pressures on certain development activities in the developed temperate latitudes, the need to develop these Arctic resources and explore for more is accelerating.

The distribution and movement of sea ice seriously impacts winter exploration and transportation activities north of the Gulf of St. Lawrence on the east and the Aleutian Islands of the west, and summer activities roughly north of latitude 70 degrees N.

Sea ice monitoring and forecasting impact transportation of exploration and development materials to the site and products from the site, providing knowledge of present conditions for navigation and predicting future conditions for route selection. This involves location and extent of navigable leads, bergs, floes, pressure ridges, and areas of weak and new or strong and old ice. Marine seismic exploration is similarly affected. Increasing use of on-ice winter seismic methods requires similar knowledge of leads, melt areas, pressure ridges, ice islands and surface roughness. Installation of off-shore platforms and loading facilities is impacted, as well as construction of between-island pipelines and overland pipelines at land-water interfaces.

Ice watch and forecasting, begun by surface methods, and later aerial surveillance, has been significantly advanced by the meteorology satellites. Minimum resolution on these, however, is about 1 km (NOAA 3-4). Landsat resolution of 30 m, and MSS discrimination of near-IR, has provided additional

benefit. Landsat follow-on, with the proposed rapid delivery of images, will prove to be even more useful.

6. Economic Considerations in Exploration

Petroleum exploration and production typically follows six stages of activity:

1) Regional geologic reconnaissance of large areas to recognize sedimentary basins and major structural features within the basins. Landsat images compiled into mosaics have proven valuable to many companies for this exploration phase. In some cases major decisions on whether to acquire foreign exploration concessions have been made on these preliminary analyses.

2) Surface geologic mapping and sampling of outcrops. Enlarged Landsat images can aid in locating areas suitable for these studies. The savings in manpower and time can be appreciable, especially in areas where base maps are poor or lacking.

3) Aerial magnetic surveys and ground-based gravity surveys are the initial geophysical reconnaissance. Trends of lineaments and structures from Landsat interpretations of stage 1 can aid in locating and orienting these surveys to obtain optimum crossing of the structural pattern. Here again the base maps derived from Landsat have been valuable aids to the aircraft navigators and field party chiefs.

4) Seismic surveys are made over promising anomalies located in the previous 3 stages. Trafficability and access information from the Landsat maps can save several days of crew time each month at a typical operating cost of $5,000 per day in isolated foreign areas.

5) Drilling of prospects that have been targeted by activities 1 through 4.

6) If the 1 to 20 odds against success have been overcome and an oil field discovered, the final stage is to produce and transport the oil to market. Preliminary pipeline route studies can be made from Landsat.

The use of Landsat data to their fullest potential for minerals exploration should produce the following economic advantages:

(1) Savings during the reconnaissance exploration stage. The savings will be in the decrease in amount of exploration effort (and cost) for this first stage of exploration. The savings will be realized mostly by the larger companies operating in remote areas of the under-developed countries

where the geology is poorly known and operating conditions are difficult and primative.

(2) Savings during the exploration of individual prospects. Savings in exploration cost can be realized by any minerals exploration group by applying Landsat data as another exploration tool. Its function would be to help eliminate unfavorable areas and permit concentration of the more expensive exploration procedures on the most favorable areas.

Sabins has addressed the common question of "How much oil has Landsat imagery discovered?" Those asking this question reveal a lack of understanding of oil exploration which involves many technical methods. Even in the pre-Landsat era it was difficult, if not impossible, to credit a discovery well to a single technology. Landsat interpretations are one of many methods employed, as described earlier. The time from beginning of exploration to drilling a well is commonly five years or more. Landsat imagery did not become widely available until the mid 1973's and industry then had to learn how to acquire, interpret, and utilize the imagery. On this time frame, the major petroleum benefits of Landsat are in the future.

C. INLAND WATER RESOURCES

1. General

The application of Landsat data to water resources management encompasses nearly all subjects on inland water resources to some degree. Water resources management begins with the watershed or drainage basin and ends with application of water by the user. The water manager must concern himself with numerous water parameters such as quality, quantity, seasonal distribution, and water loss. In moving water from the watershed to the user, he must continually evaluate collection, storage, transportation and distribution systems, control facilities and the efficiency of the total system.

The problems of surface water management vary considerably from one part of the United States to another and from season to season. In most western states water is a critical resource that must be managed within limits set by state law and interstate compacts. Surface water may be used

and re-used numerous times until it is lost through evapotranspiration back into the atmosphere or becomes unusable because of salt concentration. Use of available groundwater may be limited to withdrawal at a fixed rate based on a formula which may include saturated thickness of the aquifer and a predetermined number of years of production set by some agency. When the groundwater reservoir is depleted, land values drop and use must be changed because in most western states groundwater aquifers receive little or no recharge, and once depleted, recovery may take hundreds and possibly thousands of years.

In the northwestern, eastern and southern states, the problems with water are nearly opposite in nature. These states generally have an excess of water -- groundwater aquifers are full to overflowing and streams and rivers flow most of the year. Streams, rivers and lakes are used for many purposes, to dispose of municipal and industrial waste, as water supplies, for transportation and power generation. A major concern of the water manager here is to control and regulate stream flow, reservoir levels, water quality and thermal pollution.

Remote sensing from satellites, such as Landsat, and aircraft is directly applicable to surface water resource management. One characteristic of water that aids in differentiating surface water from land areas is the ability of water to absorb radiation in the infrared region. This characteristic increases the contrast on certain types of images sensitive to the infrared spectrum (.7 - 1.5 μm). The Landsat multi-spectral scanner covers the near infrared region (.7 - 1.1 μm) and provides images with good land-water contrast that are well suited to surface water resources management where object identification either through spectral analysis or image analysis is essential to provide accurate evaluation of hydrologic parameters.

Landsat has shown that satellite data can be applied to water resources management of both surface and groundwater. The satellite with its remote data collection platform relay capability has been proven to be versatile. Applications of Landsat data to water resource management range from watershed analysis to snow mapping and from surface water inventory to near real-time flood damage assessment. Table III-1 displays some of the demonstrated applications.

TABLE III-1

Demonstrated Key Landsat Capabilities for Water Resources Management

A. Watershed Land Use/Surface Cover and Flood Plain Studies

- Hydrologically relevant land uses and surface cover information (impervious fraction, vegetation density, etc.) including fractional watershed coverage can be obtained and displayed at scales up to 1:24,000.
- Landsat data have been acquired on a seasonal basis and compiled for engineering design and planning studies using watershed models in 1/4 to 1/30th the time required using conventional approaches.
- Costs figures range between 1-4/km^2 and cost savings could be 15-20% for the average urban watershed study.
- Quasi-operational tests have been accomplished using USDA/SCS models, USACE models, and in EPA 208 Program studies.

B. Snow/Ice Surveys

- Snowcover variations have been monitored on watersheds as small as 6 km^2 and snowline altitudes estimated with accuracies up to ± 60 meters.
- Significant correlations of early snowmelt snowcover and seasonal runoff have been obtained and studies completed showing that satellite snowcover data should improve the performance of snowcover runoff prediction models.
- A quasi-operational test of satellite snowcover observations is occurring in the Western States involving 6 Federal agencies and State agencies.
- Observations of glaciers can very effectively be acquired for mass balance, glacier movement, and inventory studies.

C. Surface Water Surveys Including Flood Surveys and Wetlands Monitoring

- Costs of surveys are 1/10th that for using conventional techniques.
- Lakes larger than 1 hectare can be detected and changes in lakes larger than 4 hectares monitored.
- Major vegetation species on Coastal Wetlands can be delineated at scales up to 1:125,00.
- Lake area estimation accuracy can be ± 8% at 5 hectares and ± 1% at 500 hectares.
- Landsat imagery assessed as a fast accurate and relatively inexpensive method of compiling flood data for disaster planning and post-flood analysis.
- Quasi-operational applications of these data have been accomplished through surface water surveys in Oklahoma and Tennessee by U.S. Army Corps of Engineers, Texas Water Right Comm., and the SCS in Oklahoma.

TABLE III-1 (continued)

D. Water Quality Surveys

- Suspended solids concentration in near surface layers can be estimated to ± 5-10% over the range from 0-900 ppm.
- Landsat data can be used in better choosing the location of in-situ measurements, identifying anomalous water quality regions, and extending monitoring to areas not normally accessible by land or boat.
- The trophic status of lakes can be surveyed quickly (re: Minnesota).

Landsat data is currently being utilized in both digital tape and image forms. To obtain maximum information from Landsat data, computer processing of digital tapes is necessary; however, manual interpretation is less costly in many cases and requires a minimum of equipment.

2. Surface Water

a. Watershed Management

The application of Landsat data to evaluation of watershed characteristics has been attempted by many agencies of State and Federal governments along with universities and independent research groups. Their primary objectives have been to predict maximum and minimum runoff values, annual runoff volume, and peak flow periods. These are the watershed characteristics which most concern the water resource manager. Through evaluation of these parameters, reservoirs, flood control structures, and water distribution systems can be adequately designed; reservoir operations can be made more efficient; maximum beneficial use of surface water can be realized; flood hazard reduced, and surface water can be more efficiently administered.

Watershed analysis and the accuracy of runoff predictions have made significant gains in recent years through watershed modeling and use of advanced computer techniques. Many of these models are formulated so that the watershed processes operating between the precipitation input and river runoff output depend upon coefficients that are related to land use and surface cover characteristics, stream order, stream length, drainage density, basin area, basin shape, slope, stream gradient, etc. Variables that must be considered in watershed modeling include precipitation (type, amount and distribution), other weather conditions and solid moisture. Research efforts have shown that Landsat can provide much of the required information through MSS images or digital tapes, and DCP's in a more timely, representative, and cost effective manner than can be achieved using conventional approaches.

b. Reservoir Management

Reservoir management, whether for water supply, flood control or both generally relies on real-time data systems. The New England Division, Corps of Engineers, undertook a study to determine the usefulness of data products received from satellites including Landsat. Some of the Landsat applications include phenomena such as:

(1) Location and coverage of surface water, especially flood and low flood periods.

(2) Icing conditions on rivers, lakes, reservoirs.

(3) Turbidity, sedimentation in lakes and reservoirs.

(4) Location and extent of snow cover.

(5) Location and extent of excessive precipitation accumulation.

(6) Tidal levels and flooding at or near hurricane barriers.

(7) Soil moisture conditions.

The New England Divisions system has been proven feasible and reliable. The Corps has stated that orbiting satellite systems can be designed that are more feasible, easily maintained, less expensive than conventional ground-based data collection systems.

c. Stream Hydrology

Large scale stream hydrologic parameters such as stream sinuosity, order, length, density, gradient, sediment load, and change, can be evaluated from Landsat data.

Flood hazard, flood damage estimates, flood plain characteristics, and flood control are potential applications for Landsat data. The New England Division, Corps of Engineers have successfully applied Landsat data combined with DCP data to many of the mentioned areas of stream hydrology for reservoir management and operation.

d. Water Quality

Water quality analysis using Landsat data is limited to those parameters that have visible signature of some type or can be correlated to some physical change that does. Dissolved solids and chemical parameters cannot be measured directly from Landsat data; however, they can be measured by remote data collection Platforms (DCP's) and relayed for correlation with Landsat data.

e. Soil Moisture

Soil moisture is one of the most important hydrologic parameters in water resources management because it is indicative of groundwater conditions and essential for determination of watershed runoff characteristics, soil infiltration rates, and soil moisture deficiency, etc. Soil moisture when combined with other hydrologic parameters can be used to evaluate recharge and discharge area of drainage basins, crop conditions, and groundwater boundary limits and conditions.

Soil moisture levels can be used in estimating flood hazard associated with precipitation events. Landsat has been shown to be capable of detecting soil moisture differences and areal distribution of precipitation events; however, Landsat lacks a real-time data distribution capability for image data. As a result, estimating flood hazard for real time applications using Landsat data is not practical at this time, but represents a potential for future systems. The data Landsat is capable of providing is valuable in estimating flood hazard through analysis of watershed characteristics and flood plain mapping.

A microwave sensor capable of measuring soil moisture would have the advantages of increasing the accuracy and reliability of evaluating soil moisture conditions on watersheds to aid in runoff predictions, in agricultural areas to determine crop conditions and efficiency of irrigation practices, in evaluating groundwater aquifer parameters, etc. In addition, such a system may have the potential of determining the water content of snow in watershed areas.

f. Surface Water Inventory

Inventory of surface water bodies larger than 0.01 km^2 appears to be operational or near operational. However, many private lakes and ponds are less than 0.01 km^2 in area. In most parts of the country construction of ponds and reservoirs is tightly regulated. Landsat data could be used to identify new construction and to regulate these small ponds with increased resolution. The proposed Thematic Mapper system should provide a great advantage in evaluating most water resources management parameters.

g. Snow and Ice Surveys

One very significant feature of Landsat's ability to record precipitation events is that snow areal extent can be readily mapped. In mountainous areas snow pack may account for 50 to 60 percent of annual runoff as in the Upper Rio Grande drainage basin of Colorado. Snow mapping by Landsat may prove to be the key for making near real time runoff predictions which are essential for efficient management of water resources. If an increased accuracy of 10 percent for runoff predictions can be realized, this could mean as much as 158,000 acre-feet of additional water could be used for irrigation in Colorado. This water could be used for increased production or to satisfy interstate compact commitments.

Accurate prediction of snowmelt runoff depends on delineating the snow line from bare ground, rock, clouds, and under tree cover, and on estimating the water content of the snow. A microwave sensor may provide water content of snow directly. Such a system is highly desirable for developing a means of snow mapping and runoff predictions in ungaged watersheds. Empirical methods for forecasting runoff based on snow cover and other hydrologic data for a basin are a reality today, but such methods are applicable to gaged basin only.

Ice conditions can be surveyed from Landsat data for lakes and pack ice. Ice conditions on lakes and rivers affect surface evaporation rates, and stream hydrology. Ice jams on rivers can produce flooding as well as barriers to water transportation. Ice on reservoirs significantly affect surface evaporation. For large and inaccessible reservoirs, Landsat images could be used to economically determine the extent of ice cover for computing evaporation losses. There are no known studies of this type.

h. Hydrologic Land Use Classification

Classification of land use is necessary in watersheds and drainage basins because land use affects runoff characteristics, infiltration and evapotranspiration losses. All of these elements are used in hydrologic modeling as part of the mass balance equation for the system. In order to achieve the greatest accuracy in modeling a watershed or drainage basin, land use must be classified and the areal intent of each class known.

Landsat data combined with extensive ground truth can be used to produce land use maps at scales as large as 1:24,000. Generation of maps at this scale is dependent upon computer enhancement and manipulation of digital data, a very costly process. However, smaller scale maps are less expensive and serve most hydrologic applications just as well, and will be appreciably easier to produce.

3. Groundwater

Management of groundwater resources presents an almost entirely different set of problems than for management of surface water resources. The basic water parameters of quality, quantity and seasonal distribution are similar for both; however, evaluation of ground water parameters is another matter. To effectively manage groundwater resources, aquifer characteristics must be established such as areal extent, saturated thickness,

boundary conditions, coefficients for storage and transmissivity, and recharge and discharge areas. Many of these characteristics, such as saturated thickness and coefficients of storage and transmissivity which must be tested in situ, cannot be evaluated through use of remote sensing techniques. Other aquifer characteristics, including recharge and discharge areas, may be evaluated indirectly from remotely sensed data through analysis of land use, vegetation, stream patterns and types, landforms, and geologic structure. Some aquifer characteristics may be evaluated directly if conditions are favorable. For example, in many western states where vegetation is sparse and geologic formation and structure are evident, aquifer boundary conditions and aerial extent may be mapped directly. Where geologic structure is apparent, aquifer boundary conditions can be estimated; and by combining all of the visible hydrologic parameters the gross ground water aquifer system may be evaluated.

D. LAND INVENTORY

1. General

Land inventory requirements have increased dramatically over the past ten years. Many programs, such as the U. S. Coastal Zone Management Act, the National Environmental Protection Act, the Army Corps of Engineers' 404 Permitting Program, the 208 element of the Federal Water Pollution Control Act Amendments, and others have elements which are still developing and therefore do not yet have specific, fully-defined requirements for data. Many programs and activities also have long term objectives for which data requirements or criteria may change over time. For these reasons and others to be discussed, there are at present few operational uses of Landsat data in the United States. However, there is a wide variety of potential land inventory-related applications of existing and proposed Landsat data, a number of techniques for which have been tested and indicate a significant future usefulness. The term "land inventory-related" could extend to cover a myriad of categories; however, we will consider here only the following seven applications:

A. Natural Resource Inventory

B. Forestry, Range, and Wildlife

C. Wetland Mapping and Inventory

D. Coastal Zone and Shoreline Mapping

E. Mapping and Cartography

F. Surface Mining Extent and Reclamation

G. Urban and Special Environments

In terms of the data requirements for each application, there are several areas of overlap -- areas where more than one application can benefit from the same data and/or criteria. There are also areas which are mutually exclusive; criteria for one application may preclude successful results from another, thus requiring a trade-off. The following section will give a brief overview of these applications.

2. Natural Resources Inventory

An expanded concern for the environment and careful planning for the wise use of our natural resources have caused both public and private agencies to face the need to provide intensive planning and management programs which meet the requirements of new state and federal laws. These laws require the establishment of baseline data accurately portraying natural conditions and allowing monitoring systems to easily identify change. Some selected examples of laws and programs which support the need for expanded natural resource inventories and/or regional land-use inventory systems follow.

a. P.L. 92-500. Section 303e of the Federal Water Pollution Control Act requires water quality plans to be developed for all the river basins in the United States. This planning process requires a careful analysis of the interrelationships between properties of the natural environment and land-use conditions, to determine how these relationships affect water quality. Provisions are also to be made for regular monitoring and updating of data. Several federal agencies, state environmental protection agencies and water pollution control boards, and regional planning agencies are involved in this program.

b. The Department of Housing and Urban Development now requires comprehensive areawide land-use plans to be completed by August, 1977 for all agencies utilizing HUD's 701 Planning Assistance funds.

c. The Federal Water Pollution Act of 1972, P.L. 92-500, Section 208, requires that state and local jurisdictions provide plans which show how the state will deal with point and non-point pollution sources. In developing such plans, the relationships between waste disposal, water conditions, land use, and natural characteristics must be carefully analyzed.

d. The Soil Conservation Service, under laws 74-46 and 89-566 has been publishing soil surveys of various counties. The data collected is to be utilized in decision-making processes involving land-use as well as agricultural practices. In addition to this, the Soil Conservation Service has made inventories to assist in identifying areas for water impoundments, recreational developments, etc.

e. The National Environmental Policy Act (NEPA) requires as part of various federal and state programs that extensive environmental impact statements be prepared before construction of projects such as highways, electric generation plants, transmission corridors, airports, parks, and other major public works endeavors. These environmental impact studies require very careful analysis of the potential effects of proposed projects on natural conditions. Again, there is a need to determine the capabilities and constraints of the landscape. This requires an intensive study of the natural resources within the area of concern.

Systematic methods for collecting, recording, and interpreting data related to natural resource conditions are increasingly needed to gain a better understanding of natural conditions for making the planning, development, or management decisions.

Most of this natural resource inventory data is presently collected either through traditional air photo interpretation techniques or specific site investigations. There has been, however, very little coordination of the data collection or planning between various agencies. What is now occurring is that Landsat is beginning to eliminate inconsistent and sometimes contradictory planning policies that result from the segmental type of data collection and interpretation presently occurring in many federal, state and local programs.

Perhaps the greatest advantage of Landsat data is that it provides a common base on which characteristics of the earth's surface can be compared to other spatially referenced data (for example, soils, geologic, agriculture data). Landsat would seem to be the ideal system for integrating land-use planning or natural resource inventory data.

3. Forestry, Range, and Wildlife

In forestry, range and wildlife management applications capability has been demonstrated to broadly stratify land areas into various vegetative cover types. The highest success in stratification has been at level I,

discrimination of forest and range from other land use; i.e., urban, agriculture, barren land, water, etc. Consistently, performance levels of 95 percent and greater have been demonstrated.

The first task in forest mapping is determination of the forest type. Although accuracies of type mapping (e.g., conifer vs. deciduous) will vary from location to location, it seems that repeatable performances can be expected from 75-95 percent.

Much like forest type mapping, forest density classification is basically a stratification procedure. Through density classifications, gross volume estimates can be made with the best results occurring in the heaviest or dense areas. Studies indicate high correlation between forest and dense forest lands as against lower correlations in medium and sparsely stocked stands from Landsat data. The deterioration in the sparse areas indicates confusion with other materials, and substantiates the problem in vegetative mapping from Landsat at a level III. Also, forest density levels tend to reflect forest stand distribution rather than trees within the stand. Any maps generated from such data form an excellent basis for designing an "... area wide, valid, forest volume assessment."

While broad general density groupings have value, the most important use of Landsat data in this regard is in conjunction with ancillary data in providing a stepwise volume inventory.

Under some conditions, Landsat is capable of detecting stress or other differences not obvious by the eye or camera. Utilization of repeat coverage as a change detection monitor thus seems to be a great potential from the Landsat system. This capability also suggests the strong possibility of early warning in areas of disease and insect infestation.

The present operational use of Landsat imagery with rangeland resource management has been virtually non-existent except for research applications. Current information on changes in rangeland use is required for proper management of these lands. The system must be able to survey, map, and monitor conditions that cause deterioration of rangeland use capability and soil productivity, and have the capability of being updated frequently.

Landscape features are a controlling factor in the interpretation of single-date Landsat imagery because it is generally agreed that landform dictates land use more than any other major factor within the range environment. Major vegetation classes tend to transgress major geomorphic provinces

as well as varying within each major land class. The type and amount of vegetation and the surface water availability also contribute significantly to major decisions regarding land use in this environment. The type of broad landform classes which can be delineated in this fashion include alluvial and floodplain lands, basin and low terrace land, plateau and upper terrace lands, and moderate to steeply sloping uplands. Only generalized maps of dominant land classes and associated vegetation types can be prepared in this environment when only interpreting one date of Landsat imagery. The use of multi-date imagery will not increase the level of detail, but it can increase the classification accuracy of major classes.

Manual interpretation of multi-date imagery can be used to assess many questions involving change. For instance, an assessment of ephemeral productivity can be made. By comparing imagery taken in the fall, prior to the initiation of ephemeral plant growth, with imagery taken at the peak of the growing period, different amounts of forage produced on different sites can be distinguished. Sites supporting a mixture of perennial shrubs and ephemerals in season can be separated from sites supporting predominantly ephemerals.

An assessment can be made of the four major events which take place within the rangeland during the spring season. First, there is the final melt of any snow pack on the major peaks of the area. Secondly, on the lower slopes and bottomlands the herbaceous vegetation grows rapidly and soon extracts most of the available moisture from the soil. Thirdly, herbaceous vegetation on drier, shallower sites begins to dry after experiencing rapid growth. And finally, surface water bodies fill with runoff water which contain a certain degree of sediment. The assessment of these changes is important because all of these factors influence management decisions of the resource specialist. Once the snow has melted, new areas are available for grazing domestic animals as well as wildlife. With the lower slopes experiencing peak forage production, rangeland animals must be managed soundly to ensure proper use of the available forage. With the lower slopes already showing signs of drying, and reservoirs at their peak, care must be taken not to overgraze those regions close to the water supply areas. With the drying of the herbaceous component, the fire danger becomes higher as the season progresses.

Multi-stage computer classification techniques using single-date Landsat data can provide the basis for the production of a general inplace

vegetation map, correctly delineating and identifying major vegetation types, such as brush, mountain shrub/juniper, conifer, meadow, rock or bare ground, and water, in areas where these types dominated the spectral response of the individual pixels.

4. Wetland Mapping and Inventory

The U.S. Fish and Wildlife Service 1956 inventory of wetlands estimated that there were 74.4 million acres (29.9 million ha) of wetlands in the United States. The inventory included only wetlands in the conterminous United States and most wetlands less than 40 acres (16.2 ha) in size were excluded from the survey. Since 1956, many acres of wetland habitat have been destroyed as the U.S. population increased. Also in recent years, our understanding of wetland values has increased and state and federal governments have enacted legislation to protect wetlands (e.g., wetland laws, critical areas legislation, EPA section 404, Corps of Engineers mandate). These laws generally require classification and inventory of wetlands as the first step in the protective process. In addition studies of wetland hydrology and ecology provide needed information for the management and evaluation of wetlands.

Remote sensing is becoming one of the most frequently used and practical tools for wetland inventory and mapping. It also provides some of the additional information on ecology and hydrology needed for wise resource management.

The present tasks to be done are as follows:

* Wetland inventory and mapping (includes identification, classification and boundary determination)
* Wetland ecology and hydrology studies
* Wetland evaluation

a. Wetland Mapping and Inventory

Wetland mapping and inventory are presently being conducted by both federal and state agencies on an operational basis. In order to inventory and map, wetlands must be defined and classified.

The U.S. Fish and Wildlife Service has recently developed a new classification system as the basis for a new National Wetland Inventory, the "Interim Classification of Wetlands and Aquatic Habitats of the United States". This system will provide a uniform basis for comparison of map

and inventory products at the national, regional and state level. It should be noted that the new FWS system includes many habitats (for example, rocky shores, beaches and deep-water bottoms) not traditionally considered wetlands. The present report will focus on the more conventional wetlands concepts (vegetated wetlands).

Presently, most wetland inventories are based upon aircraft photography supplemented by ground surveys. B/W panchromatic photographs have traditionally been used for mapping (for example, by SCS, USGS), but in recent years research has been conducted into the use of other film/filter combinations or aircraft scanner data. These include natural color, color IR, multispectral B/W and aircraft multispectral scanner. As a result of this research, coastal wetlands, and in a few cases, inland wetlands are being, or have been, operationally inventoried and mapped using low-altitude color IR (New Jersey, Delaware, New York), natural color (Maryland), B/W panchromatic (New York, Massachusetts, Rhode Island), or ground survey supplemented with available photography (Virginia).

To date, there are no documented operational programs using Landsat for wetland mapping. The use of Landsat data for wetland inventory and mapping is generally still in the experimental phase. Coastal marshes have received the most attention to date. Recent work has demonstrated the potential of both imagery and digital data for mapping these wetlands. Little work has been done with Landsat data in inland wetlands, except that incidental to general land-use mapping. Landsat data has potential for inland wetland inventory if spectral parameters are worked out and boundary dynamics problems are solved. As a result of current Landsat system limitations, the present FWS National Wetlands Inventory will utilize aircraft photography rather than Landsat imagery. Hopefully, future updates will be able to use improved Landsat data.

b. Wetland Ecology and Hydrology Studies

Many of the investigators referenced above have used aircraft data in a variety of ecological studies. Among these are studies of species composition of wetland vegetation, wetland productivity, wildlife habitat diversity, impact of man-made structures on wetlands and mosquito breeding habitats. Comparatively few studies have been carried out on wetland hydrology and wetland management.

c. Wetland Evaluation

Wetland evaluation is presently done by wetland type and vegetative composition. Studies using remote sensing to identify and map wetlands have the potential for use for wetland evaluation.

5. Coastal Zone and Shoreline

Significant progress has been made in recent years in demonstrating the use of electromagnetic remote sensing instruments to derive information about the character and conditions of coastal waters. The present state-of-the-art for collecting, processing, and analyzing remote sensor data has evolved from aircraft and spacecraft experience in which Landsat data have been a significant factor. In particular, Landsat imagery has been useful in mapping and surveying coastal features by state, federal, and private interests involved in coastal management activities which have been accelerated since the U.S. Coastal Zone Management Act of 1972.

In addition to the coastal land inventories and shoreline applications, the physical properties and processes of coastal waters have been observed and measured by remote sensors including the mapping of sub-surface topographic and bathymetric features; location and measurement of pollutants; areas of high bio-productivity using color indications of chlorophyll concentration; surface circulation and currents through tracing of sediment and dye movement; shoal locating; and depth determination.

a. Shoreline Changes

Storm induced changes in shape, dimension and location of shoreline features are dramatic, rapid and often considered disastrous. The storm of March 1962, which affected the east coast of the United States from South Carolina to Massachusetts caused the loss of life, millions of dollars of investments in homes and businesses and created a multi-million dollar requirement of federal, state and private funds to partially restore the shoreline to its pre-storm condition and provide protection against further storm damage. Such storms, although unusual, do occur yearly on a smaller scale and create problems for those who live on or use the shoreline. Moreover the normal day-to-day forces, i.e. waves, tides, currents, constantly alter the shoreline and cause erosion on one portion, accretion in another and siltation of harbors, inlets and estuaries.

Presently, the means to measure such changes use conventional methods of topographic and hydrographic surveying techniques which are time consuming, expensive and limited in areal scope. These methods, because of the inherent restrictions of men and equipment, cannot measure changes in the shorelines on a broad regional basis and cannot be accomplished repetitively on an economically sound basis.

Landsat imagery, with its repetitive and large areal coverage has shown that it is feasible to detect changes in the shoreline, but the normal day-to-day modifications of the shoreline are smaller than the specifications of spatial resolution of the existing satellites. Major erosion of beaches approaching 15 meters or less is common and it would be advantageous to be able to accurately detect and measure such changes. Increased spatial resolution of the proposed Landsat will allow a greater capability to measure the dimensions of shoreline features and changes in such features but still is not adequate to do so accurately.

b. Coastal Land Form, Land Use, and Land Cover

Elements of the landscape are altered less frequently as one moves inland. Tidal actions and erosion are examples of natural change factors which prevail less as one goes inland. Man's actions in modifying the environment are more random and depend on the level of his activity. Based on the alteration frequency, frequency of monitoring requirements is greater nearest to shorelines. Based on the analysis of high altitude aircraft data, this study recommends the use of Landsat imagery to gain metric imagery over large areas at greater frequencies and at less cost than aircraft data can provide. Landsat data can fulfill these needs except where higher spatial resolution or greater than 9-day observation frequencies are needed.

c. Coastal Circulations, Currents and Sediment Transport

Most of the sediments which compose the shoreline are derived from upland areas, delivered to the shore by rivers and streams, distributed along shore by currents, deposited and eroded by waves and currents and are normally in constant motion. Movements of individual sand grains may in themselves be small but generally the shoreline is in a state of instability. The prime forces causing this motion are waves and wave induced littoral currents. Natural features such as inlet and river

mouths and man made such as harbors interrupt this movement of littoral materials and create problems for man. In one place there may be too much material and in others not enough.

In using the shoreline it is imperative that a thorough knowledge of the movement of littoral materials is available for proper planning and for use of the coastal zone. If sufficient knowledge is not available, improper and incorrect solutions for problems can be made or misleading applications of solutions can be selected.

The construction and maintenance of navigation facilities for industry and pleasure is a multi-million dollar business and the successful continuation of such facilities depends on the success of man's attempt to change nature by either dredging littoral materials from harbors or construction of massive coastal structures such as jetties or breakwaters. Too often a solution which did as it was intended at a specific location is selected for another location, only to fail from a lack of understanding of the hydrodynamic forces present in the coastal areas.

The use of Landsat imagery has assisted in expanding the knowledge of nearshore water circulation and in some respect by inference the movement of littoral materials. Imagery has revealed the areal extent of sediments discharged by rivers under both normal and flood conditions; the circulation of coastal waters and the sediments suspended in such waters; the effect of natural and man made coastal structures in diverting or converging currents, the effect of thermal enhanced discharges from electrical generating plants and the dispersal of man's wastes dumped at sea.

6. Mapping and Cartography

a. Hydrographic Charting

The Defense Mapping Agency, in conjunction with the international hydrographic community, has the responsibility of providing accurate and inexpensive charts for marine navigation. A significant problem is looming on the technological horizon for which Landsat Multispectral Scanner (MSS) data may prove to be the only effective solution. Within the next decade, low cost, Global Positioning System receivers will be providing ships with real time, precise positional data. Navigators will use this data to plot their courses and for their navigation. Current charts, for

the most part, cannot support this type of navigational accuracy. Currently, only about 20% of the world's oceans have been adequately surveyed with sonar and modern navigation systems. Additionally, there are vast amounts of ocean areas that have never been surveyed by any means. There are literally thousands of "doubtful dangers" marked on charts that have never been verified. Islands within 100 kilometers of the U.S. coast have been reported to be as far as 2-1/2 km off from their charted positions.

The present Landsat Multispectral Scanner (MSS) is providing a partial solution to this dilemma. The recent joint NASA-Costeau Experiment in the Caribbean has proved the capability to chart significant shoal features with MSS data. Evaluation of worldwide water transparency indicates that this approach can be used in most oceanic waters away from the continental shorelines and in some instances and areas, even these coastal waters can be plumbed.

b. Presurvey for Planning of Hydrographic Surveys

Detailed hydrographic surveys generally involve charting at 1:10,000 to 1:100,000 scale and the performance of accurate presurveys allows the expensive boat survey operations to be optimally performed. A commonly quoted figure is that the survey boats spend 50 percent of their time in shallow water collecting 10 percent of the data. With presurvey by Landsat data, channels open to most vessels can be located and defined for detailed surveys and thus boat survey time can be materially reduced This in turn increases the cost effectiveness of the survey operation.

c. Aeronautical Charting

Landsat data have proved most useful for revising the representations and positions of features such as mountains and water bodies, and for the depiction of vegetation boundaries. For many remote and poorly mapped areas of the world, Landsat provides the only readily available data from which small scale charts can be compiled or revised.

d. Small Scale Image Mapping

Image maps and mosaics have been produced from Landsat data by numerous agencies. In the United States, the principal agencies mapping with Landsat data include the U.S. Geological Survey (USGS) and the Soil Conservation Service (SCS).

The regularity and consistency of the Landsat 1 and 2 orbit has allowed a set of 251 nominal ground tracks to be established and plotted

on a map of the Earth. Image centers are generally repeated to monitor coverage over the nominal scenes thus defined. These nominal Landsat scenes do not overlap and each scene is identified by the geodetic coordinates or by a path/row number.

e. Map Revision

Revision is an integral part of all mapping and charting programs. Adequate image resolution is a primary prerequisite for map revision tasks. Present Landsat imagery is adequate for revising landforms, vegetation patterns, hydrological features, and other relatively bold items. Revision of cultural features such as roads, railways, towns, etc. is not generally possible with current Landsat data, nor will the smaller IFOV of 30 m planned for Landsat follow-on be sufficient for revision of cultural detail.

7. Surface Mining Extent and Reclamation

In this environmentally conscious period, one cannot disassociate surface mining and reclamation procedures. Historically, and even in recent years, examples can be cited where surface mining has been done without any or with minimal attempts to reclaim the disturbed areas. This is no longer true since most states now require that reclamation plans be submitted prior to issuing mining permits. There are presently (March 1976) thirty-five states that have state surface mining regulation acts.

Landsat research efforts in surface mine monitoring have been conducted with the following objectives:

- To demonstrate Landsat capability of mapping acreages stripped and disturbed by surface mining operations.
- To monitor changes in stripping and secondary effects of mining on the environment.

It is the general conclusion of most researchers that Landsat remote sensing data, combined with appropriate low and high level aerial data, (ground truth) could be a useful tool in monitoring and mapping surface mining and reclamation progress. All of the research conducted used analysis of digital values of the reflectance levels obtained from computer-compatible tapes (CCT's) for the areas involved. The greater the surface areas under study, the higher the degree of accuracy obtained between comparisons of ground truth and digitally calculated areas from

Landsat images. In dealing with small areas (several acres or less) the limiting factor for Landsat data use is the spatial resolution of the sensors.

One of the most comprehensive research efforts to date on the overall application of remote sensing data (Landsat, Skylab and aircraft imagery) to environmental problems relating to coal mining was done in the eastern Appalachian coalfields and anthracite areas of Pennsylvania. The researchers conclude that at present for year-round monitoring of surface mining Landsat imagery is of limited value. However, the authors feel it may be quite useful for annual updates, if appropriate baseline data is available.

The improved resolution of the Landsat follow-on Thematic Mapper will be helpful, but surface mining and reclamation regulatory users need to be introduced first to the existing systems to determine their usefulness, prior to considering more sophisticated systems, which may or may not be required.

In summary, there is presently no operational use of Landsat data by state or federal agencies in monitoring surface mining activities and their impact on the environment. Despite possible cost benefits to potential users, use of Landsat data requires too many institutional changes. As summarized so aptly by Amato, "...Integration of remote sensing monitoring systems into the state mining regulatory programs depends upon many factors that differ substantially from place to place due to state requirements and the environment... a real question still exists, however, as to what extent analysis of satellite imagery would replace or supplement current monitoring procedures and what the real cost saving would be."

8. <u>Urban and Special Environments</u>

Urban land use in a modern industrial state unquestionably extracts a greater toll from the land, the air, and the life forms (human and otherwise) than any other form of existence that man has devised for himself. When one considers that our 76 percent of the population of the United States resides in 276 metropolitan clusters whose total territory encompasses less than 2 percent of the nation's land area, the impact is all too apparent. In selected small areas, the residential population densities exceed 250,000 persons per square mile. The direct and secondary effects of these living conditions have a demonstrable effect on both the physiological and psychological well-being of humans.

As a result of the better understanding of these effects and the increasing scarcity of the resources of urban life as it has developed, it is rapidly becoming necessary to understand and measure the complex social, economic, and geographic interrelationships of the metropolis. Of necessity, most of this work must be done by microanalysis. Even with the most powerful computers, this analytic approach cannot process and classify the data in a timely manner. The use of remote sensing, with the level of capability incorporated in the Landsat follow-on program offers some hope of slicing the Gordian knot of monitoring the dynamics of metropolitan life.

The analyses performed by the user agencies and firms are transferred to state or local agencies for implementation of various data-gathering or planning functions. These user agencies and firms vary greatly in budgets, skilled staff, data processing equipment, and sophistication in obtaining, handling, and making use of land use and related environmental data. However, the user institution typically has some sort of information system for dealing with data of the type described. Some such information systems are highly advanced, making use of modern spatial data-handling equipment and procedures, including large digital computers linked to forecasting and other modeling capabilities.

Many studies in the metropolitan environment, of necessity, require an analysis of a large proportion of the entire area. For instance, drainage or watershed studies or, alternatively, transportation studies require that a large area be viewed as a whole within the large metro context. Sometimes, these can be derived from small area data by aggregating upward. However, the level of detail of the data need not be as fine as is usually collected at a tract or block level. Consequently, much of it often can be derived from space imagery without sacrificing detail.

One of the conditions necessary for realizing urban applications is the incorporation of the development of a total geographically based information system as part of the Landsat follow-on activities. Such a system must provide users with (1) a set of tabulations for small area data that will report standard land use category data items as units of area (e.g. hectares or acres) per census tract, (2) a map of land use

patterns with census tract boundaries overlayed, and (3) with increased imagery resolution, an interactive information system that will allow satellite data to be used at the neighborhood or block level.

Urban planners define three levels of a geographic hierarchy of areas or "building blocks" for categorizing the land use/land cover data: the ownership parcel, the census tract, and the metropolitan region. It is strongly recommended that the coordination and delivery of data satisfying users' needs at all three levels be kept together in a single program, rather than separating these data on the basis of which will be supplied by aircraft and which by Landsat. Keeping the three levels together in a single coordinated effort will have two important benefits: it will allow realization of economies through minimizing collecting of duplicative or overlapping data sets, and it will keep the users whose requirements can at present only be satisfied by aircraft data in close touch with advances in satellite capability, thereby increasing the likelihood that these users may move toward future utilization of Landsat follow-on.

E. AGRICULTURE

1. General

The demand for agricultural information is well documented. In the foreword of the seminar papers prepared by Assistant Secretary Robert W. Long for the United States Department of Agriculture's conference on Retention of Prime Lands, he states: "A frustrating lack of data prevents a clear picture of either the current situation or the probable future amount of land available or needed for agricultural production." An unsettling conclusion which arose from the conference indicated that technological improvements alone can no longer be relied upon to overcome production losses from a diminishing supply of arable land. Recommendations from that conference clearly identify the need:

* For improved information concerning the earth's potential for producing food, feed and fiber;
* To monitor potential agricultural production from planting to harvesting.

There is a growing consensus that remote sensing can:

* Be used as a tool to improve the quality of our global

information in these areas;

* Make a significant contribution to our agricultural management decision process.

Potential users of agricultural remote sensing data cover a wide spectrum from: hundreds of thousands of farmers; to large agribusiness organizations; to local, state, federal, and international decision makers. Levels of operational applications vary according to the specific needs of this diverse user group. To make Landsat follow-on data compatible with the needs of this unique user community is a difficult task.

To date, operational applications of remote sensing techniques in agriculture have typically depended on aircraft data collection systems. Landsat data have received limited operational use in agricultural programs, particularly in areas requiring sophisticated multi-stage satellite, aircraft, and the use of statistical models. Landsat potential can be significant, however, particularly when dynamic resources are evaluated. Reasons often stated for this lack of operational application include:

* Excessive time-delays in the receipt of data products after overpass;
* Low spatial resolution of products;
* Inappropriate spectral resolution of data product;
* An overall lack of information on the part of potential users.

In the process of reviewing possible worthwhile applications of remote sensing in agricultural production, a number of basic guidelines must be recognized and used in the review process. The realities of the circumstances under which remote sensing will be used in agriculture must be considered, and provide the basis for consideration of each major application. It must be recognized that:

- There will be supplemental information available to persons making management decisions.
- Ground truth data (site visit) will be an integral part of the practices of most applications of remote sensing in agriculture.

- Positive identification is not usually possible in remote sensing data (insect species, crop species or variety, disease pathogen, etc.) and collateral data are essential.
- A very short delivery time is critical for most effective use of remote sensing in agricultural; a 48-hour delivery time frame is required to be effective for many agricultural applications.
- Accurate calibration, registration and geographic referencing will establish rigid requirements to be met by the system.
- Historical and supplemental documentation should be maintained to support the use of and increase the value of the data over time. Decisions based on an extended time frame will require this.
- Satellite acquired data must be converted to information for use in the management decision process; without conversion and use, there can be no claim of benefit attributed to remote sensing.

It would be possible to list well over 100 applications that could be accomplished with the remote sensing capabilities proposed (and planned) for the follow-on satellite project. When the similarities between many of the applications and especially their dependence on the capability or characteristics of a specific sensor are recognized, this list may be reduced considerably. Thus the applications may be considered more in the form of groups of activities or uses. As a result, for example, crop stress may be considered as one application, even though it may involve a great number of crops, for reasons related to disease, insects, moisture, frost, or heat.

Basically, the various applications reviewed here were considered in relation to the practices to which they could be applied within the normal management practices of the agricultural sector of our economy. The point of application of the information was considered (federal agency, state, local, industrial, farmer). As a result, a relatively small number of headings for

which remote sensing could supply a variety of information have been identified. These include:

- Crop stress
- Temperature effects
- Climatic effects
- Water management
- Worldwide crop production

2. <u>Crop Stress and Crop Management</u>

In addition to adequate remotely sensed imagery, the crop stress analyst needs supplemental ground truth for selected areas in the form of soil and salinity maps, weather data, large scale color and color infrared imagery, crop calendars, planting configurations (flat vs. bed, etc.), typical crop rotations and acreages for the areas. He also needs much supplemental information for his area to allow crop stress to be properly interpreted from Landsat images. The identification of areas of stress in crops is a major source of useful information from satellite imagery of importance to decision makers during the crop growing season. Since stress typically is evident on a diurnal cycle increasing during the day, an afternoon crossing time would be preferable for its detection. The associated cloud build-up and haze problems are recognized; a trade-off study would be of use here.

a. <u>Insect and Disease Stress</u>

Landsat follow-on may be expected to be of very limited value for detecting most stress damage due to the relatively small area of a field or plant involved, at least during early stages of the condition. However, where large areas of leaf canopy are affected, detection should be possible. Correct interpretation will require that the imagery be employed by interpreters familiar with the management intricacies of modern agriculture as well as the region involved.

Probably the most critical point that can be raised with regard to the use of remotely sensed data in stress determination is the throughput time of the data to the user in a form sufficient for the information to be worthwhile. For some applications, such as moisture assessment, to be used operationally the data must be received in hours after sensing. However, other intra-season management such as that indicating occurrence

of rainfall, measuring soil temperature for indicating when soil is warm enough to plant crops, studying occurrence and pattern of freezes, monitoring thermal pollution, detecting springs and subsurface flow into lakes, rivers and oceans, estimating evapotranspiration of farmland, forest, and rangelands, estimating water evaporating from lakes, ponds, and reservoirs will require data. These data may profitably be received in somewhat more leisurely time scale, with the urgency dependent on the particular degree of volatility of the condition being monitored and the urgency of the need to react to the data.

b. Soil Moisture Stress

One of the most serious aspects of excess water in root zones is that of controlling fluctuating water tables. Most experts estimate that roots of most agricultural plants are materially damaged if submerged in water for more than about five days during the hot part of the growing season.

In the case of irrigated crops, uncontrolled, fluctuating water tables usually result from over-irrigation. When water tables are allowed to rise and remain in the root zone for an extended period, the submerged roots are often killed. When this occurs, the plants become shallow-rooted and must be irrigated accordingly - usually more frequently, which in turn further aggravates the high water table problem. Furthermore, such plants no longer have root systems capable of providing nutrients for maximum growth. In addition, the water at the shallow water table often is high in salinity allowing excess salts to accumulate in the soil profile by the upward water movement associated with capillary rise.

One of the main considerations in growing crops on poorly drained soils concerns the measures necessary for controlling the water table. On irrigated projects the main emphasis must be on careful control of the application of irrigation water. Widespread use of satellite imagery to determine when crops should be irrigated will result when the data are received within a few days after the flight was made. This one innovation could result in appreciable conservation of our limited water supply and the energy necessary to move this natural resource.

Various crops used as indirect indicators of water table depths respond differently because of variable physiologic response of different

crops to environmental conditions. Cotton on the one hand has been found to be extremely responsive to changes in environment as exhibited in spectral and thermal characteristics and is an excellent indicator crop for high water table, salinity, and evapotranspiration measurements. Sorghum is intermediate in response and corn is one of the poorer indicators of stress conditions. Estimates of depth to water table made from data collected on the Thematic Mapping Mission should be made based on measurements in fields of the same crop. This will also minimize differences in emissivity.

Several investigations indicate that thermodynamic conditions creating surface temperature anomalies for bare soils are dissimilar under conditions of water tables very near the surface on the one hand and deeper than about 1.5 meters on the other hand. This results in the apparent respective optimum times for thermal sensing of predawn for deeper water tables and mid-afternoon for very shallow water tables.

c. Saline Stress

Saline soil conditions reduce the value and productivity of considerable areas of land throughout the world. Salinity commonly occurs in irrigated soils because of accumulations of soluble salts in soil profiles over extended periods introduced with the irrigation water. Many dry land soils contain excess salts supplied by the soil parent material and concentrated by water movement. The injurious effects of salts are normally caused more by a limiting of the availability of soil water to plants than by direct toxic effects. Under highly saline conditions the osmotic concentrations of the soil solution may be so high that plants suffer for lack of water on soils that actually seem to have an ample moisture supply.

At present, detection of saline problems is handled on a piecemeal basis. Often by the time salinity problems are recognized, the application of corrective measures is too late. The greatest problem is where entire fields may be nearly uniformly affected by salinity, in which cases farmers may not recognize the reason for the reduction in yield they may be experiencing.

Plants are frequently good indicators of conditions that occur below the soil surface. The root systems of plants explore a rather large

soil volume so that plant canopies are more representative of the site conditions than is the soil surface. Many crops growing in saline areas exhibit marked visual symptoms of moisture stress. Salinity may influence leaf color, physiological structure, leaf thickness, pigmentation, hydration, and transpiration. These factors, in turn, can affect the spectral and thermal properties of plants.

3. <u>Temperature</u>

Preliminary analysis indicates that minimum temperature is the primary factor related to spring wheat planting variation and wheat development through heating. After heating, maximum temperature is a principal element in advancing the development stage toward maturity. Temperature sensitivity by this model shows that a 1-degree Fahrenheit temperature bias during the spring season produces approximately a 2-day difference in maturity date.

Thermal infrared aircraft missions for detecting shallow groundwater have been successful in South Dakota. These studies showed that a surface emittance anomaly could be used to locate near-surface groundwater in glacial drift. However, the principles involved in heat storage and transfer also apply to shallow unconfined water tables under conditions experienced in many agricultural areas.

A knowledgeable observer, with the improved resolution imagery of Landsat follow-on should be considered as an important factor in evaluating the world's irrigated agricultural resource and the related water supply. His use of the temperature sensitive band will provide an additional tool for use in the water-oriented activities of agriculture. This will greatly aid in the monitoring of water bodies and moisture laden soils.

4. <u>Climatic Modeling</u>

Computerized models which relate the impact of weather on crop yields are constructed by comparing many years of historical data on weather and yield and establishing a statistical linkage between them. Different models are used for different crop areas, and the models allow for a trend to higher yields due to changes in farming methods such as new grain varieties or greater use of fertilizers. Weather data for the current year (beginning when the previous crop is harvested) are collected

by crop district, county, or equivalent crop area and are used with the regression model to project the yields for the coming harvest.

The weather data include monthly averages of temperature, precipitation, and in some instances, potential evapotranspiration, which serves as a measure of stress to which the crop is being subjected. In addition, for LACIE, weather parameters which are covered include weekly surface temperatures, cloud cover, cloud type, precipitation (type and intensity), and major weather systems affecting the regions under analysis. Although a considerable amount of weather data and analyses are derived from the World Meteorological Organization Global Telecommunications System (WMO/GTS), much use is made of satellite photos in assessing the climate pattern.

To be an effective tool for assessment work, remotely sensed data must be available on a timely basis and in a form which will facilitate integration with available ground truth information. To be timely means that the output must be relatively current. A 10-day to 2-week delay greatly diminishes the value of these data for assessment work. A 1 to 2 day delay would probably be acceptable.

Operational meteorological satellite digital data provides for the rapid throughput of the information, but lacks the necessary spatial density. The Landsat follow-on Thematic Mapper will provide the necessary spatial density but will lack continuous coverage of a given agricultural area and fast throughput (every 9 days). Information from the Thematic Mapper will also have to contend with the problem of cloud contamination. This is an ever present problem with surface temperature determination, and will be a critical problem with limited area coverage and a nine day return period.

5. Water Management

An approximation of the total water demand for an agricultural region can be made if the major crop species are identified and an irrigation efficiency factor, for that area, can be developed. To a less accurate degree even the binary classification of irrigated/non-irrigated lands can be employed for this purpose if some collateral information is available to develop the average regional water application rate. In determining what the total water requirements are for a specific area, the mechanics of water application must also be considered in order to establish a reasonable determination of the current irrigation efficiency employed. Is field flooding

common or is the irrigation water applied through use of open ditches or pipes? Therefore, water supply inventories coupled with the water demand estimates and water application practices are important parameters necessary to the efficient prediction of agricultural yield. For instance, if the required water supply is not available for any particular year, reductions in total yield can be predicted.

A discussion of the measuring and estimating of the water supply has been given in the section on inland water resources, and so will not be repeated here. However, the subject of subsurface water mapping for agricultural water table management was not covered there.

In many cases benefits obtained from removing excess water have been very conspicuous and have led to a hundredfold increase in land values. Yet in other cases the usefulness of such drainage has not always been clearly demonstrated. An excessive lowering of the water table may actually lead to a decrease in crop yield in cases where certain crops utilize non-saline soil water from the capillary fringe above water tables. It is obvious that continuous monitoring such as can be provided by remote sensing is necessary in managing water tables in relation to optimum crop production. Management can provide optimum water table depths and prevent fluctuating to the extent that root systems are damaged.

The season in which the missions are scheduled for mapping water tables is an important consideration. If crops are used as indicators of subsurface conditions the best response can be obtained when the canopy nearly or entirely covers the bare soil surface, and when the root system is developed to substantial depth. This will generally be in July or August in most northern latitudes. Further research may show that thermal sensing of bare soils may yield additional information done in late spring when water tables are usually lowest.

6. Worldwide Crop Production Estimation

Some of the tasks involved in implementing a global crop production inventory system involve research to:

- Address the spatial/locational dimensions of estimating a variety of crops worldwide.
- Assess the range of spatial resolutions which could result in more accurate estimates of crops in a variety of geographic environments.

• Examine the overall effects of the emission and reflection properties of the wide variety of physical and biological parameters which influence crop type determination accuracies.

• Test the validity and probability of acquiring adequate multitemporal data in a variety of environments.

• Improve data gathering, processing, analysis, and dissemination procedures.

• Integrate meteorological satellite, Landsat series, and other high resolution imaging systems data with collateral material into crop production models.

It can be appreciated that these tasks go beyond the use of Landsat or Landsat follow-on data as the sole remote sensor input. Indeed, to accomplish the goal preparation must be made to examine complex mixes of systems with:

• Global and/or regional orbital characteristics.

• Spectral sensitivities from the visible into the microwave.

• A variety of spatial resolutions.

• Coverages designed to maximize the potential of cloud free data during critical stages in the growing cycle.

• Modeling systems designed to accommodate inputs from a variety of sources at a variety of scales and to produce accurate estimates.

The above listing indicates that putting together the proper mix of systems and data for global production estimation is a complex process requiring much ingenuity and allocation of resources. Despite these cautions, it is the opinion of many researchers in the field of agricultural remote sensing that crop production forecasts can be accomplished if proper procedures are developed and followed.

Past and present research indicates that remote sensing offers considerable potential for supplying much needed information on agricultural production. In the future remote sensing will play an ever increasing role in production estimation as we refine our modeling techniques and increase the capabilities of a variety of sensor systems to provide data input to forecast models. Many factors are involved in the estimation of agricultural production. In addition to the factors outlined in the previous sections, many researchers are convinced that the accuracies of agricultural surveys can be significantly improved by combining multispectral and multi-

temporal input data. Crop calendar parameters should also be employed to provide the inputs necessary to differentiate between crops with similar spectral but different phenological characteristics.

The LACIE program addresses many of the problems involved in providing a world-wide crop production estimate. In this respect LACIE is currently heavily involved in the complex modeling of a variety of important parameters. Results to date appear encouraging, and it is significant that a considerable committment has been made to the LACIE program by a number of agencies.

Significant progress has been made toward achieving a level of scientific and technical know-how sufficient to accomplish the task of estimating the worldwide production of major food crops. The Landsat follow-on system will significantly improve the potential for achieving this goal. Considerable research, however, is still required to operationalize the proper mixes of models which include a variety of types of remotely sensed data coupled with collateral material (including field sampling) to provide the locational, spectral, spatial, temporal, and resolution components necessary to accomplish this task.

F. INFORMATION AND MANAGEMENT SYSTEMS

1. Summary and Assessment

Statewide and regional computerized natural resources information systems are becoming important decision-making tools in a number of parts of the country. Many of those currently being designed are making specific provisions for inclusion of Landsat data as one component of the data base. Thus organizations are committing to an expensive information system based in part on the continued availability of Landsat data.

Specific deficiencies in the present Landsat system, from the standpoint of data utilization in an operational information system, include:

* Delays in delivery of data - delays in data delivery are troublesome, although not, in most cases, the overriding consideration in the use or nonuse of Landsat data.

* Potential discontinuity in availability of data - the potential discontinuity -- or even discontinuation -- of Landsat data availability has apparently discouraged some potential users from detailed evaluation of its utility.

* Lack of geometric correction and georeferencing of data - lack of geometrically corrected and referenced data causes innumerable problems among present data users. The process of correcting and referencing the data is time consuming and expensive -- even prohibitive in some cases.

The Landsat follow-on program is designed to alleviate many of the real and/or perceived problems of the present system.

Expedited data delivery, while not critical for all users, will be an important factor in the decision of many organizations -- particularly those concerned with transient phenomena -- to adopt the operational use of Landsat data. Any improvement in the present distribution system, therefore, would be beneficial to all users, present and potential.

Elimination of the threat of data discontinuity would be a substantial psychological boost to those organizations who are now heavily committed to Landsat data use. In all likelihood many other organizations which are interested, but as yet uncommitted, would reassess their positions with respect to the Landsat program.

The third improvement -- geometric correction and registration of the data -- is probably the single greatest benefit to be provided to data users who are concerned with overlay of Landsat with other data. There are several directions that the process of geometric correction could take -- reformatting of data to North-South pixels, providing ground reference information for georeferencing, providing data with a specific map projection, or development of user-oriented correction software that is fast and efficient and, therefore, inexpensive to run. The crucial element does not seem to be so much exactly which of the above (or perhaps all) schemes are adopted. What is important is that some means of efficiently and inexpensively getting geographically referenced and geometrically corrected data to the users be implemented.

In spite of the vast improvements that would result from implementation of the above elements, some problems would still remain. These would be largely in the area of technology transfer and the increased processing costs and time envisioned for the six band, higher resolution data. Some form of dimensional reduction of the data may eliminate or reduce cost and time problems, but the technology transfer problems would still remain. A possible solution to the technology transfer problem would be establishment of urban or regional information centers -- perhaps at state universities which have major data processing centers and experts in many disciplines. Another

solution might be the designation of technology transfer agents consisting of individuals and/or firms with remote sensing experience to help operational agencies formulate and solve their problems.

Throughout the planning for Landsat follow-on, one consideration should be forcefully acknowledged: Landsat data frequently is and will continue to be auxiliary data -- to be only one component of a natural resources information system, for example. Finally, it should be noted that it is not easy for a user to reap the benefits of satellite data. The user must make a substantial commitment of man-hours and/or funds just to be capable of using available systems. For many applications the user must interface with the system directly, implying that the user must buy time on someone else's system or he must implement a system in-house at a substantial capital investment. These steps require time, patience, and often spoon-feeding the users. It is naive to think that a user overnight is going to make a 180° turn, invest great amounts of time, manpower, and money, and dive head-first into a new way of doing his business, unless the benefits to himself are conclusively demonstrated.

The above discussions demonstrate two things about the Landsat program generally and Landsat follow-on in particular. First, the technology transfer program is still in its infancy even though a steadily increasing number of organizations are utilizing the data. Second, and perhaps more importantly, adoption of the Landsat follow-on program will tend to promote the transfer of technology which will, in turn, increase the benefits to be derived from Landsat follow-on. The factors which will promote technology transfer are:

* Assurance of data continuity
* Increased resolution and geometric fidelity
* Increased timeliness
* Compatibility with increasing numbers of resource-oriented information systems

2. Present Information and Management Systems

The present user data processing systems are divided into two parts:

a. Visual image interpretation (raw imagery and computer enhanced imagery)

b. Computer analysis of digital data

Visual image interpretation, which has been the more widely used technique, ranges from direct visual interpretation of an individual image to the

use of optical systems (zoom transfer scopes, color additive viewers, and density slicers) which provide enhanced images or composites of images to facilitate visual interpretation. Most of the visual interpretation has provided qualitative information at a small scale that serves as a screening device to indicate areas that need more detailed analysis through larger scale imagery or ground surveys.

Recently the user community has begun to appreciate the full capabilities of Landsat data by computer processing of the digital multispectral data. Computer processing allows the user to take full advantage of the spatial and spectral resolution of the Landsat data. Computer processing provides greater geometric precision, more accurate land cover maps, and enhanced photo products for visual interpretation. As more users are becoming aware of the digital processing techniques, they are choosing to use digital information extraction techniques over the visual interpretation procedures. More and more users are realizing that there is more information on the digital tapes than in the photographic products. Once a user has obtained a useful, informative digital output product, he has the basis for a geo-based grid cell digital data base. This digital data base has much more potential than a color coded land cover classification map. This geographic data base can be merged with other available data (topography, soils, geology, etc.) and manipulated, analyzed, fed into models, etc. The possibilities for manipulation, analysis, and simulation have great potential. The capability for monitoring change is greatly enhanced. The basis exists for more thorough, precise policies to be formed based upon more sophisticated methods of analysis. The amount of information available combined with the numerical analytical options should improve resource management decisions.

Statewide and regional computerized natural resources information systems are becoming important decision-making tools in a number of parts of the country. Many of these currently being designed are making specific provisions for inclusion of Landsat data as one component of the data base. Georgia is actively planning for an information system which will include Landsat data as one component. Other states such as Mississippi, Minnesota, Maryland, and Ohio have already begun to implement information systems which include Landsat data. Louisiana and Pennsylvania are developing programs to use Landsat data as a method of updating the LUDA information produced by USGS.

In contrast to the above, there is evidence that other states are hesitating to employ Landsat data in any operational effort because of the "research" nature of the project. They fear that an operational satellite system will be drastically different from the present, or worse still, there will never be an operational system. In either case, these agencies feel that their present efforts with respect to Landsat might prove to be wasted.

Potential Landsat data users (who were not funded by NASA) at one time had to wait weeks or even months for the data. Many agencies deemed the delay unacceptable and initially rejected the use of the data for any operational purpose. As data delivery improved, however, some agencies began to take a second look at the possibilities inherent in the data. Continued improvement in the rate of delivery of the data as proposed for the Landsat follow-on program should significantly aid operational agencies -- particularly those concerned with short-term or rapidly changing phenomena -- and can only mean that more agencies will find use of Landsat data a better alternative for, or supplement to, their present data.

3. Restrictions and Needs

The need for additional sensor bands, improved geometric and radiometric fidelity, and more frequent data has been previously documented and need not be repeated here. The technical parameters of the Landsat follow-on program should overcome many of the objections that have been expressed about the present Landsat program and will benefit most of the organizations using the data in digital form.

In the past a major problem with use of Landsat data to provide one component of a geographically-oriented natural resources information system has been geometric rectification. This process has been time consuming, expensive, and often inadequate. Promised improvements in system performance and rectification of the digital data to a user-specified coordinate system will largely overcome these problems.

Some states and user agencies are committing to an expensive information system based in part on the continued availability of Landsat data. Failure to implement a Landsat follow-on program would therefore entail substantial additional effort and expense in redesigning these information systems. Any agency committed to operational use of the Landsat data in any form would also experience revisions in methodology and added expenses in

converting to another data source. Perhaps of even more importance is the fact that the Landsat follow-on program will encourage many new users who previously have been reluctant to become involved because of a fear that there will be no continuity of data acquisition.

As more and more users are looking to digital techniques to extract information from the digital data, they are realizing that there is a lot of data to process in just one scene. If they want to do change detection by comparing two scenes, there is twice as much data to process. The data are expensive to process and requires sophisticated software. If the user doesn't have the capability to process the data in his own organization, he has to go to a contractor. If the user is not familiar with these computer techniques, their capabilities, and especially limitations, then he has a difficult time contracting to get a useful product; and he can easily become disenchanted if the product delivered by the contractor is not what the user needs. Indeed the determination of whether a product is useful or not is often subjective and hard, if not impossible, to specify in a contract.

On the other hand, if a user is familiar with the computer analysis techniques but does not have the software available in-house, he, too, has to contract. As a knowledgeable user, however, he knows that these "automatic" land use classification systems are really not automatic at all. A significant amount of ground truth, including high quality aerial photography, is required to "train" the computer, and an individual familiar with the geographic area being looked at and/or trained in a specific discipline must interact with the machine to effect a useful and accurate final product. But the ground truth or aerial photography may not be readily available, and the contractor more than likely does not have anyone familiar with the area being studied or the background required to know if the computer output is accurate. This means that the user himself may have to interact with the computer. But to do so may require a significant amount of training for the user before he would be capable of carrying out the computer analysis procedures. Such a user may decide that the most cost-effective way to get the Landsat data to meet his needs is to implement a digital analysis system in-house and provide a central service for his own organization. Not only will this require a considerable investment, but organizationally it may not be possible. Some decentralized organizations have autonomous field offices that frown upon any centralized activities. The point here is that there is a big gap between the Landsat digital data and the user obtaining a useful informative product on a continuing basis.

As far as computer processing is concerned, the gap between the users and available systems addressed above will be widened by the Landsat follow-on due to increased data volume, more sophisticated processing techniques, and increased cost. Although many of the existing digital analysis techniques can handle six spectral bands, the increased volume of data for a Landsat follow-on scene will drive up the costs of computer output products. The increase in spectral and spatial resolution will increase the number of distinguishable land cover types; however, since the computer must be "trained" to identify each of these types, the amount of man-machine interaction will increase and will be more complex. In other words, the information content of the data is increased in the Landsat follow-on, but so is the data processing required to extract the information.

The most pressing problem is bridging this gap between the users and the available systems for analysis of remotely sensed data, even though many of the currently available systems are adequate for extracting available information from Landsat data. The primary reasons for the gap are (a) lack of sufficient user education, training, and exposure to the current capabilities, (b) the fact that the information extracted from the satellite data does not fit into the users' standard operating procedures, and (c) the limited number of analysis systems (both optical and digital) available to the users. The degree of technical sophistication required to implement such digital systems in-house has reached a point that is out of reach of many potential users. Since for many users the Landsat data is ancillary data, they are not willing to invest the time and money necessary to use the Landsat data properly.

Many potential users' standard operating procedures and decision-making processes do not include digital analysis. It is naive to think a user is going to change his standard operating procedure to accommodate digital satellite data. Rather, this potential user might well judge the satellite data not applicable to his problems, although, in fact, the data are applicable in his decision-making process.

Solutions to these problems include increased education and more pilot projects to tailor the information extracted from satellite data to user standard operating procedures. More efficient classification algorithms to reduce computation costs would be beneficial. In the case of the increased volume of data from the Landsat follow-on, good dimensional reduction techniques to allow processing of less data without losing information could result

in significant savings. This will lead to an increased user demand for analysis systems which will, in turn, lead to more systems becoming available.

4. Landsat follow-on Program

While many of the benefits to be derived from the Landsat program were mentioned in the previous section on restrictions in the present system, a more detailed explanation of these benefits is needed. Furthermore, additional provisions in the Landsat program need to be made to insure maximum transfer of the Landsat follow-on technology to users. This section, therefore, concentrates on the additional benefits to be derived from Landsat follow-on and the technology transfer mechanisms by which these benefits may be realized.

For many of the users and potential users of Landsat and Landsat follow-on data, the satellite data is the ancillary data. This fact is the reason it is so important to get the information derived from Landsat data into the existing routine procedures of the potential users. Conducting pilot projects specifically for this purpose may be the best way to gain user acceptance of Landsat data.

Technology transfer, therefore, becomes vitally important in NASA's efforts to increase the usefulness of the Landsat program generally and, in particular, to insure that maximum benefits are derived from the Landsat follow-on program. Increased technology transfer is required for two primary purposes:

1. Increase the use of Landsat data for operational purposes.
2. Insure that maximum benefits are derived from Landsat follow-on.

A possible solution to the technology transfer problem would be the establishment of urban or regional information centers -- perhaps at state universities which have major data processing centers and experts in many disciplines. Another solution might be the designation of technology transfer agents consisting of individuals and/or firms with remote sensing experience to help operational agencies formulate and solve their problems.

One concern of many users is that the data be acquired at the appropriate time. If one is concerned with the impact of a natural disaster, data must be acquired near the time of its occurrence. In this respect, the designed 9-day repetitive passes of Landsat follow-on represent an improvement over Landsats

1-C. For many applications, data from several different periods through the year may be required. Other applications require data from year-to-year. The Landsat follow-on system is particularly well suited for meeting these demands.

NASA could provide assistance to potential users to aid them in setting up their digital processing facilities. Such assistance might consist of consulting services, improved manuals to cope with problems of tape reading and interpretation, and special-purpose software (especially for new-generation mini- and micro-computers). This service would not include advice or guidance as to purposes for which the data might be used; that is and should remain a user function. The body of existing literature is ample for a serious data user to establish the potential uses of the data and the interpretive processes that might be applicable to fit his particular needs, but technology transfer will be necessary for him to accomplish his aims.

Although not necessarily a part of the Landsat program, the presentation of information based upon Landsat data should be given some attention. The decision makers to whom this information is addressed are rarely specialists in the technology involved and have a limited amount of time for examining information. Thus, it would seem desirable for NASA to assist users in identifying the most appropriate methods for summarizing, generalizing, and extracting critical elements of information.

Some of the benefits discussed above might result from a simple decision to continue the Landsat program in its present form. Landsat follow-on, however, has specific improvement programmed into the system to increase user benefits still further -- particularly among users employing digital data. Among the specific major improvements impacting on users' information and management systems are:

* Increased spectral and spatial resolution of the data
* More timely distribution of data to users
* Geometric correction of digital data supplied to users

Taken together these improvements should be quite beneficial to Landsat data users in operational agencies.

During the current Landsat program numerous resource-oriented state and regional information systems and/or data management systems have been developed. Many of these systems use, or contemplate the use of, digital Landsat data as one component of the data base. A major problem with users has been the perceived incompatibility of the Landsat data with other components of the data base because of insufficient resolution and/or lack of adequate registration

of the data. Supplying geometrically corrected Landsat data with improved resolution would save countless hours of labor and computer time in creating, maintaining, and updating the land cover portion of these data bases.

While potentially very large, the benefits to current users with existing information systems would likely be dwarfed by the benefits to those new users who would find Landsat follow-on an acceptable source of land cover data. Even though the increased geometric fidelity and improved spatial resolution would not always be required in these proposed information systems, their mere availability would probably prompt many users to accept the data as an input to the data base. In addition, the assured continuation of Landsat-type data would help justify to the user the initial costs of including these data in the data base.

Many federal and state programs are tending to make some type of resource-oriented information system a necessity for operational government agencies. Thus the need for land cover data in such systems will probably increase manyfold over the next several years. Landsat follow-on will provide the assurance of continuity, as well as the increased technical capability, to justify its use by a majority of the resource-oriented information systems.

In summary, there are several benefits to the Landsat follow-on program which tend to promote the transfer of this technology to an increasing body of users. The primary benefits are:

* assurance of data continuity,
* increased resolution and geometric fidelity,
* increased timeliness,
* compatibility with increasing numbers of resource-oriented information systems.

All of these benefits should contribute to increased acceptance of Landsat data as one primary input to the decision-making process at all levels.

PART 2

MINERAL AND PETROLEUM EXPLORATION

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CHAPTER I

INTRODUCTION

The work of the committee of the Applications Survey Group is reported in four main sections entitled Mineral Exploration, Energy Resources Exploration, Environmental Geology, and Mapping and Interpretation. Each section was written by a subgroup consisting of four to nine scientists which are knowledgeable in that subject. A common form was completed by each subgroup, summarizing their evaluations of Landsat follow-on (formerly called Landsat D) in comparison with Landsats 1, 2, and C, as well as with desirable characteristics of hoped-for geological satellites of the future. The most general of these four sections is Mapping and Interpretation, which includes elements of all the other sections, plus some general considerations.

The primary purpose of this report is to estimate the importance of Landsat follow-on for geologic problems. In doing so, this committee could not, in good conscience, avoid listing desirable characteristics of a satellite system which would be designed primarily for the problems geologists are attempting to solve by remote sensing methods. It is our unanimous opinion that the optimization of satellite systems through the 1980 time frame of Landsat follow-on for vegetative problems is seriously short-sighted and unsupportive of some major national goals, in light of the world's very real and impending shortage of natural resources over the next half-century. From a technical standpoint, geological problems require more sophisticated satellite systems than agriculture or other vegetative-oriented disciplines, primarily because rocks and minerals provide useful diagnostic information over a much larger spectral range than plants and because the three-dimensional scale of geologic features, unlike vegetative features, is large enough to warrant the need for stereo coverage at the spatial resolutions typical of satellite scanning systems.

CHAPTER II

MINERAL EXPLORATION

The demand for mineral raw materials to sustain the industries of the United States and other industrialized nations has increased tremendously since the beginning of this century. In most readily accessible parts of the world, unexploited, easily discovered surface or near-surface ore deposits are now rare or non-existent, and concealed deposits must be sought.

Fortunately, much is now known about geologic features which control the occurrence of ore deposits. Although only direct techniques (such as the outlining of a magnetic anomaly associated with a magnetite deposit) provide specific information on the location and extent of an ore deposit, techniques that provide regional geologic information can add to the understanding of the origin and distribution of ore deposits and, hence, are useful in their exploration.

Remote sensing shows promise in identifying areas favorable for the location of mineral deposits, and in ruling out areas of little promise, thus enabling a more selective use of costly ground exploration. Specifically, the synoptic view from remote sensors in space permits delineation of distinctive geologic features of many kinds known to be associated with various types of mineral deposits. Examples of such features are faults, folds, distinctive rock belts, ground altered by mineralizing solutions, topographic characteristics, and vegetation habit. Before the information can be used effectively for exploration, the relationship with a "target" -- an ore deposit, oil field, concentration of construction materials, or other extractable resources -- must be established. All degrees of relationships can exist.

The need for these data is made even more critical by the fact that our mineral resources are non-renewable and a complete and immediate inventory of such resources is critical to their proper management.

A. SURFACE MATERIALS COMPOSITION

The most promising techniques for acquiring information about the chemical and mineralogical composition of surface materials from

satellite-borne instruments are based on measurements of the following physical parameters:

1. visible and near-infrared spectral reflectance
2. thermal inertia
3. thermal-infrared spectral emittance

Because of the large effort that has been focused on analysis of Landsat-1 and 2 MSS data, the use of 0.5 to 1.1 μm region is best established. It is now clear that processing the MSS spectral radiance data permits subtle distinctions among rock and soil units that cannot be achieved through analysis of unenhanced images or color photographs.

In stretched-ratio images concentrations of iron-oxide minerals can be distinguished from other mineral assemblages (Rowan, et al, 1974; Vincent, 1975; Offield, in press). This is important, not only because of the association of limonite with some hydrothermal alteration zones, but also because it illustrates the potential for using spectral data for estimating surface composition. This technique is limited by the present MSS bands, because the spectral reflectance of terrestrial rocks and soils is dominated by iron-absorption bands, and the wavelength positions and intensities of these bands are commonly related to impurities or weathering phenomena rather than bulk compositions. Thus, with the exception of limonite, the MSS data can be used with careful processing and analysis to discriminate some materials, but it does not permit identification.

Addition of spectral bands near 1.6 μm and 11 μm and imaging at both 11:00 am and 11:00 pm with the Thematic Mapper would markedly improve the capability to discriminate surface materials. Averaged 0.45 to 2.5 μm field spectra for hydrothermally altered and unaltered volcanic rocks in Nevada shows that the 1.6 μm region is a window between iron-absorption bands and hydrous-absorption bands at shorter and longer wavelengths, respectively, (Rowan, 1972). Consequently, reflectance contrast between these broad categories of rocks is highest in the 1.6 μm region. Another advantage of the planned 1.6 μm band is that vigorous vegetation is darker in this region than most rocks, especially hydrothermally altered rocks. This characteristic should allow discrimination of altered rocks in areas of denser vegetation cover than is possible with present MSS data.

Thermal-inertia measurements permit discrimination of surface and near-surface materials that cannot be achieved using any other remote sensing techniques (Pohn, et al, 1972; Watson, 1975; Kahle, et al, 1976). Moreover, the compositional information obtained is highly complementary, rather than redundant, to techniques that depend on spectral reflectance differences.

Thermal inertia is partially dependent upon rock density. Moisture content also exerts an influence. Under reasonably dry conditions, distinctions such as limestone and granite vs. dolomite and quartzite, shale and marl vs. limestone and granite, and basalt and amphibolites vs. ultramafic rocks should be possible because of mineralogically related differences in density and thermal properties. Also, some surface materials are distinguishable because of their different moisture-retention properties.

Studies of thermal inertia have not included altered rocks, but consideration of mineralogical and porosity changes which occur during alteration indicates that some altered rocks should be distinctive. In general, thermal inertia might be expected to increase with increasing alteration intensity due to decreasing porosity and increasing quartz content.

Comparison of the average reflectance spectra for rocks with the proposed Thematic Mapper spectral bands shows that only the iron absorption bands and the 1.6 μm window are included in the sensitivity range of the Thematic Mapper. No radiation will be measured in the 2.2 μm region. Therefore, critical information pertaining to hydrous rocks will not be available. The practical consequences of this design are that (1) unaltered limonitic (or hematitic) anhydrous rocks (such as ferruginous sandstone and tuff, which are unimportant for most minerals) will not be distinguishable from limonitic altered rocks, (important for base metal deposits), and (2) unaltered anhydrous rocks that are highly reflective in the 1.6 μm region will appear similar to important iron-poor, hydrous, altered rocks. Thus, problems of major economic importance which have already been encountered with Landsat-1 and 2 data will remain unresolved.

Additional support for the 2.2 μm band comes from analysis of Skylab S-192 spectral radiance data by Marrs and his associates (1976). Of the visible and near-infrared spectral bands, contrast between sedimentary rock units was found highest in the 2.2 μm region, although contrast was also high in the 1.6μm region. This observation is consistent with the presence of hydrous (shale), anhydrous (sandstone), and carbonate (limestone and dolostone) rocks in the sedimentary sequence.

The rationale for thermal-emissivity ratioing rests on the fact that some rocks depart significantly from black-body behavior in the 8-to 14 μm region, resulting in an absorption (or reststrahlen) band. This phenomenon is most prominent in silicates, and its wavelength position can be related to the composition of the rocks (Lyon, 1964; Vincent and Thomson, 1972; Hunt and Salisbury, 1974). Multi-thermal channels permit a separation of compositional and temperature differences among geologic targets. Two crucial questions can be answered by monitoring multiple spectral bands in this region: (1) is the material a silicate or non-silicate, and (2) if it is a silicate, what is its general composition?

The thermal-infrared band with 120-meter resolution offers the best thermal data yet available. Specific applications for uranium exploration will probably center on definition of lithologic variations in potential host strata, especially where standard geologic mapping is difficult. USGS studies show that paleochannel-fill units, which are exploration targets, can be mapped in detail within a broad tufaceous claystone belt in South Texas. An unproven possibility may be discrimination of altered ground in which alteration involves change in porosity and clay content, and/or cementation mineralogy. For such applications, single nighttime thermal images may not be adequate, but the day-night coverage will permit thermal-inertia mapping. The thermal-inertia data will enhance the ability to discriminate among subtly different geologic materials, and provide a measure of compositional differences; an important step toward remote identification of materials.

B. DETECTION AND INTERPRETATION OF IGNEOUS INTRUSIVES

Many of the important mineral deposits of the world are associated with intrusive igneous bodies. Of great importance are porphyry copper

deposits within igneous bodies of intermediate to felsic composition. In the enclosing rocks commonly found peripheral to these intrusives are deposits of base and precious metals. Where igneous bodies intrude carbonate rocks, deposits of tungsten, silver, and base metals may form within the surrounding zone of metamorphism.

Completely different types of mineralization occur within mafic and ultramafic igneous intrusives (chromite, platinum, magnetite, ilmenite, and diamonds). In addition, mineral resources may be produced by surface weathering of specific intrusives (nickeliferous laterite, bauxite, and kaolinite).

Using presently available Landsat images it is commonly possible to delineate igneous intrusives (Sawatsky, et al, 1975). This involves conventional interpretive techniques based on such features as differences in rock structure, weathering, and selectivity of vegetation growth. Discrimination of rock types or alteration associated with mineralization can be made on the basis of spectral information properly combined and enhanced. Study of satellite images thus provides a basis for identifying promising exploration areas in which necessary field data can then be acquired to confirm or deny mineral potential.

The principal contribution of the planned Landsat follow-on to the delineation of igneous intrusives will lie in the increased resolution of the Thematic Mapper. The increase in detail thus gained will be offset, in large part, by the higher sun angle during midday passage. In desert areas, thermal data probably will serve to distinguish many intrusive bodies from surrounding rocks, and will help to discriminate among different types of intrusive rocks. The added 1.55-1.75 μm band may aid in defining intrusives of different iron-mineral content than surrounding rock.

The ideal geology-dedicated satellite would provide sufficient additional bands in the near and thermal infrared to (1) allow a distinction between silicates and enclosing non-silicates, (2) permit distinction between the silicates diagnostic of felsic, intermediate and mafic rocks, and (3) show the presence of serpentine and other hydrous minerals which are preferentially formed by alteration which accompanies several types of mineralization. The first two tasks above can only be accomplished with two or more channels in the 8-14 μm thermal

infrared region. A single thermal channel will not perform these tasks.

The brecciated and fractured rocks below and around impact structures provide conduits and traps for ore-forming fluids. Much of the world's nickel and cobalt is produced from a probable impact structure at Sudbury, Canada, and the gold is being mined in the Ishim ring structure, another probable impact structure in north-central Kazakhstau. The Carolina bays in the Carolinas and Georgia, long-suspected impact structures, produce much of the peat in that part of the U.S. Over 800 of these have been located on Landsat images. Space photography is an excellent tool for finding such circular structures.

C. TECTONICS

Geologic structures that influence the location of mineral deposits include faults, shear zones, joints, and other fractures. Faults range in length from a few hundred metres to many kilometres and, likewise, in displacement from a few centimetres to hundreds of metres; folds range from a few centimetres to many kilometres between crests or troughts. Many of these structural features can be mapped effectively from space (Hodgson, 1976).

Using new concepts of "continental drift" or "plate tectonics", many geologists postulate a relationship between major crustal breaks, igneous activity, and ore deposits. Structural geologic information extracted from data provided by space-borne remote sensors is being used to attempt to unify the "classical" concepts and the newer plate tectonics hypotheses.

Aerial photographs provided a new dimension for the study of structural features, and as the altitude to which aircraft could operate increased, coverage of larger areas became possible, and so did the mapping and correlation of structural features over considerable distances. Photographs and images from space platforms cover much larger areas than aerial photographs (34,250 km^2 for a Landsat image versus 535 km^2 for a U-2 photograph) and this synoptic view is invaluable for regional geologic studies because it provides a view of a much larger area and permits correlation of structural features over much greater distances than by using aerial photographs. This is a great advantage

in (1) identifying linear features, outcrop patterns, and discontinuities, all of which may be structurally significant; and (2) in establishing regional relationships between structures and provinces.

One of the most basic types of remotely sensed information of use in minerals exploration is a sense of the geologic trends or "grain" of a new area. In regions that have been subject to considerable tectonic deformation, erosion-resistant stratigraphic units provide a pattern which may be too subtle to be apparent on topographic maps, aerial photographs, or most satellite images. These patterns are often readily discernible, however, on present images, at very low sun angles, even in heavily forested terrain. Mineral deposits localized by particular strata can thus be traced over very large areas, and ground sampling programs planned. Regional folding patterns can be determined, and mineralization of the type that occurs in the axial areas of large, tight folds can be located. Discordant intrusive bodies, and their associated mineralization, can be detected by their interruption of strike belts.

An improved recognition of this grain, and of faults, lineaments, or intrusives which cut across it, can come from: (1) sun angles of 10^{o} to 25^{o}; (2) digital processing of MSS data to stretch contrast, enhance edge detail, and enhance linear features; (3) an improvement in scanner resolution; (4) possible new spectral ranges of scanners; (5) thermal scanners which may identify differences in heat retention of different rock types, or the vegetation characteristic of different rock types, or the vegetation characteristic of different rock types; (6) possible future satellites equipped with terrain enhancement radar with low depression angle; and (7) stereoscopic coverage. Any or all of these seven new capabilities could significantly enhance the utility of satellite imagery for mineral exploration.

D. EROSIONAL AND DEPOSITIONAL FEATURES

Depositional features of economic potential include glacial deposits, alluvial fans, stream terraces, playa lakes, and deltas. These are features where economic deposits of precious metals and/or nonmetallic minerals may be concentrated by primary deposition or secondary enrichment.

Erosional features are important in mineral exploration because they provide evidence as to surface condition, recent morphologic history, and mechanisms of possible redistribution of material. One of the most important aspects of erosional morphology is the tendency for stream valleys or other surface discontinuities to form along zones of weakness in the Earth's crust. These same zones also may have served as conduits for groundwater or hydrothermal fluids, or they can be critical components of geologic structure. In either case, they may be used as exploration guides.

Both erosional and depositional features are identified from aircraft or satellite images, mostly on the basis of surface pattern and topography. Three image characteristics are of prime importance in identification and mapping of these features: (1) a reliable presentation of normal tonal values and/or colors, (2) stereoscopic presentation of the scene, and (3) a regional perspective. High spatial resolution, multispectral and digital data, and repetitive coverage are all of secondary importance in the identification of depositional and erosional features. Digital analysis commonly is not required, but can be useful in enhancing surface textural features.

E. VEGETATION

Vegetation masks soils and rock outcrops. It has long been considered an impediment to geologic mapping and exploration. However, vegetation can be used as an important indicator of the underlying geologic terrain. Many ore deposits are concentrated along fractures in the Earth's crust. Where such fractures are water-rich, they are often marked by healthier and more abundant vegetation.

Variations in vegetative cover also indicate differences in soils which reflect differences in the underlying rock units (such as in the Powder River Basin, Wyoming; Offield, 1975), and accreting shorelines (i.e. those along the east coast of the United States where valuable titanium deposits were found). Local, anomalous vegetation patterns may also serve as indicators of anomalous concentrations of heavy metals in ground-water (metal poisoning) or nutrient-deficient parent rocks (such as serpentines and other ultrabasics).

The present Landsat systems and the planned Landsat follow-on are designed for discrimination of vegetation. The proposed system

will offer some improvement by addition of the 1.6 μm band and improved resolution for use in this application.

F. ECONOMIC CONSIDERATION

The use of Landsat data to their fullest potential for minerals exploration, should produce the following economic advantages:

(1) Savings during the reconnaissance exploration stage. The savings will be proportional to the decrease in amount of exploration effort (and cost) for this first stage of exploration. The saving will be realized mostly by the larger companies operating in remote areas of the under-developed countries where the geology is poorly known and operating conditions are difficult and expensive.

(2) Savings during the exploration of individual prospects. Savings in exploration cost can be realized by any minerals exploration group by applying Landsat data as just another exploration tool. Its function would be to help eliminate unfavorable areas and permit concentration of the more expensive exploration procedures on the most favorable areas. Any company (no matter how small) can utilize both black-and-white and color images at reasonable costs. The larger companies will be more inclined to attempt the use of more sophisticated techniques of ratioing and image enhancement.

Actual monetary savings are difficult to assess and virtually impossible to document. Based on an expenditure of $10 million per year for exploration by a large international mining company, an expected increase in efficiency of 20 percent through the use of Landsat imagery in ruling out unfavorable areas and selecting the most promising areas is not unreasonable. This would result in a savings of up to $2 million per year. Five companies together would produce a savings of $10 million per year. Using the same reasoning, but with an expected increase in efficiency of only 10 percent for exploration in the United Sates (a not unreasonable estimate), ten domestic companies, each spending $5 million per year, would experience a total savings of $5 million per year. Over a ten year period, the total international and domestic savings of only 15 companies would total $150 million.

Another important consideration for mineral exploration and development is more efficient planning that might result from accelerated discovery of ore bodies. For example, in Georgia, where recent discovery of a carbonaceous clay (an excellent light-weight aggregate) deposit

was made near a rail line that was abandoned and dismantled only two years ago. These deposits, currently uneconomic, would have been economic had they been discovered in time to save the line. Re-establishment of the rail line now would involve unacceptable costs.

Additional savings can be expected by the use of Landsat follow-on data during the development and operational stages of mineral extraction. These savings will come from more efficient operations resulting from better site selection for processing facilities, waste disposal areas, and other development associated with a major mine.

TABLE II-1
SATELLITE EVALUATIONS FOR MINERAL EXPLORATION

Good (Neutral) Detrimental
3 2 1 0 -1 -2 -3

	Tectonics and Intrusives and Impact Structures	Surface Materials and Alteration	Deposition and Erosion	Vegetation	Groundwater	Average					
LANDSAT 1 and 2											
80 m Spatial Resolution	1	1	1	-1	1	0.6					
Signal/Noise - Moderate	2	0	1	2	2	1.4					
Spectral Range 0.5 - 1.1 μm	2	-2	1	2	2	1.0					
Repeat Coverage	3	3	3	3	3	3.0					
182 x 182 km mi. Format	3	3	3	3	3	3.0					
Mid-morning 9:30 a.m.	3	2	3	1	2	2.2					
Digital Tapes - Raw data	2	3	2	3	3	2.6					
* Data Delivery as presently experienced	0	0	0	0	0	0.0					
* Image Quality as presently available	-3	0	-3	-3	-3	-2.4					
Incidental Stereo	-3	-2	-3	-1	-3	-2.4					
Geometry - Excellent	3	2	3	3	3	2.8					
LANDSAT C											
Add: 10.4 to 12.5 μm	1	0	1	1	1	0.8					
* Digital Tapes, Corrected	3	0	3	3	3	2.4					
* Data Delivery, Rapid (48 hr.)	0	0	0	0	0	0.0					
RBV Panchromatic	3	2	3	2	2	2.4					
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	3	3	3	3	3	3.0					
Add: Blue Band (water penetration)	0	1	2	1	1	1.0					
Add: Near IR (1.6 μm - mineral)	3	3	3	3	3	3.0					
Program Continuity	3	3	3	3	3	3.0					
Near-Noon - 11:00 a.m.	-3	3	-3	3	-1	-0.2					
Signal/Noise - Improved	2	3	2	3	2	2.4					
Geometry - Degraded at lower altitude	0	0	0	0	0	0.0					
10.4 - 12.5 μm Day-Night coverage	3	3	3	3	3	3.0					
Resolution - better than 30 m	3	3	1	3	2	1.4					
Additional Spectral Bands											
Passive Microwave	1	1	1	1	2	1.2					
Radar	3	0	3	2	2	2.0					
Laser Topog. Profile	3	0	1	1	0	1.0					
Fraunhoffer Line Discrim.	0	3	0	3	1	1.4					
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	2	3	1	1	1	1.6					
8.2 - 9.4 μm (with 10 - 12 μm)	2	3	1	1	1	1.6					
Different Variable Time of Day											
Very low sun angle	3	-3	3	-3	1	0.2					
Night (for thermal IR)	1	2	2	2	2	1.8					
Non-Sun synchronous	2	2	2	1	3	2.0					
Day + Night IR (Max T)	3	3	3	3	3	3.0					
Stereo Coverage - complete w/vert. exag.	3	2	3	1	3	2.4					
* Additional Pre-processing of digital data											

* = Ground Station Function

TABLE II-2
APPLICATION ASSESSMENT TABLE

Application:

Description of Mineral Exploration Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Tectonics		
Linear and curvilinears structures, strike belts. Rock-type boundaries.	Geomorphic pattern (changes, contrasts)	Considerable detail of topographic pattern will be discernible at 30 m resolution.	Resolution increase will be helpful; higher sun angle will be harmful for distinguishing topographic alignments. Stereo coverage would be highly desirable.
Structure zones with water concentration.	Soil Moisture patterns.	Broad soil moisture patterns will show, particularly in night thermal data, and should be enhanced by thermal-inertia mapping from day-night coverage.	120 m resolution should be okay for discriminating many soils or exposed rock units, but may not be sufficient for detecting narrow water-rich fault zones of low to moderate contrast against surroundings.
	Vegetation (feasible)		
Vegetation patterns and textures, areas of different populations.	Spatial textures and edges of similar textures.	Populations and their edges can be well defined (fewer "mixed pixels"). Day/night thermal coverage is much more useful than day or night alone.	Feasible with Landsat 1 and 2.
Local presence of desert type vegetation.	Spatial pattern of reflectance levels.		Clearly improved with better spatial resolution.
Seasonal (and/or daily) growth and death pattern ("green" wave and "brown" wave).	Temporal change of reflectance (both positive and negative)		
Vegetation vigor, stress, poisoning local population anomalies.	Local, often subtle variations in reflectance, usually seasonal (perhaps daily) difficult to define and very often not with large regional extent.		
	Surface Materials and Composition		
Areas of contrasting spectral reflectance (particularly alteration zones).	Spectral reflectance differences.	Digital data will permit computer enhancement for spectral-reflectance unit discrimination. Increased resolution will permit subdivision of altered-ground areas. Band 1.55-1.75 μm provides important new capacity.	Extremely important band (2.2 μm) still not available; no capability for 2 thermal channel ratios for detecting emissivity variations.
Water-retention characteristics or temperatures of dry surface materials.	Surface temperature patterns.	Night thermal and day/night coverage for thermal inertia mapping will provide excellent capability.	

TABLE II-2 (Cont'd)

APPLICATION ASSESSMENT TABLE

Application:

Description of Mineral Exploration Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Groundwater		
Fracture systems.	Geomorphic pattern, linear and curvilinear elements.	Considerable detail of topographic pattern will be discernible at 30 m resolution.	Resolution increase will be helpful (10 µm) would be even better. Higher sun angle will be harmful for distinguishing topographic alignments (less than 20 would be desirable). Stereo coverage highly desirable.
Vegetation habit.	Reflectance groupings (including temporal changes) textural character.	Spectral bands should be excellent; resolution will improve present texture-mapping capability. 9-day repetition should be adequate (certainly better than 18-day).	
	Depositional and Erosional Features		
Glacial and alluvial deposits, playas, erosional lines.	Topographic pattern; near-surface moisture variations.	Bands should be adequate for needs. Day/night thermal coverage will be marked improvement.	Higher spatial resolution thermal data desirable for distinguishing among unconsolidated materials of economic interest. Higher resolution and stereo coverages would aid in distinguishing materials and erosional lines.

CHAPTER III

ENERGY RESOURCES EXPLORATION

A. PETROLEUM (ON SHORE)

1. Structural Studies

Petroleum exploration and production typically follows six stages of activity; for companies that have begun using satellite data:

1. Regional geologic reconnaissance of large areas to recognize sedimentary basins and major structural features within the basin. Landsat images compiled into mosaics have proven valuable to many companies for this exploration phase. In many cases major decisions on whether to acquire exploration concessions must be made on these preliminary analyses.

2. Surface geologic mapping and sampling of outcrops. Enlarging Landsat images can aid in locating areas suitable for these studies. The savings in manpower and time can be appreciable, especially in areas where base maps are poor or lacking.

3. Aerial magnetic surveys and ground-based gravity surveys are the initial geophysical reconnaissance. Trends of lineament and structures from Landsat interpretation of stage 1 can aid in locating and orienting these surveys to obtain optimum crossing of the structural pattern. Here again the base maps derived from Landsat can be valuable aids to the aircraft navigators and field party chiefs.

4. Seismic surveys are made over promising anomalies located in the previous 3 stages. Trafficability and access information from the Landsat maps can save several days of crew time each month at a typical cost of $5,000 per day in isolated foreign areas.

5. Drilling of prospects that have been targeted by activities 1 through 4.

6. If the 1 to 20 odds against success have been overcome and an oil field discovered, the final stage is to produce and transport the oil to market. Preliminary pipeline route studies can be made from Landsat images and environmental impacts assessed.

The foregoing sequence of exploration stages and Landsat utilization are not hypothetical; a number of oil companies are known to procure and use large numbers of Landsat images and digital tapes. Chevron Overseas Petroleum reported at the NASA Symposium on Remote Sensing Applications in Houston on their use of Landsat in exploring and acquiring new concessions in Kenya (Miller, 1975). Wildcat wells are currently being drilled (Stage 5). In Egypt Santa Fe Minerals correlated structural features interpreted from Landsat images with trends defined from gravity and aeromagnetic surveys (Bentz and Gutman, 1976).

Sabins (1975) has addressed the common question of "How much oil has Landsat imagery discovered?" Those asking this question reveal a lack of understanding of oil exploration which involves many technical methods. In the pre-Landsat era, it was difficult, if not impossible to credit a discovery well to a single technology. The time from beginning of exploration to drilling a well is commonly five years or more. Landsat imagery did not become widely available until the mid 1973's, and industry then had to learn how to acquire, interpret, and utilize the imagery. On this time frame, the major petroleum benefits of Landsat are in the future. A final point is the concern over lack of oil industry publication describing their applications of Landsat. In addition to the Kenya and Egypt examples, Halbouty (1976) describes the correlation between circular anomalies and salt dome structures on the U.S. Gulf Coast. Many industry interpretations of Landsat are not published because oil geologists are loath to endure the red tape of rewriting, drafting and editing material for publication. This is commonly a stronger restraint than company concerns over proprietary data.

The above applications are for Landsat 1 and 2. Many companies have already acquired their imagery of their areas of interest. This is shown by the fact that the oil industry has purchased the largest volume of data from the EROS Data Center. It is unlikely that they would acquire repeat coverage from future satellites unless there are significant improvements in spatial resolution and spectral coverage.

There is a trend toward utilization of digital tapes for in-house processing on the computer facilities of most companies. Future satellites should provide CCT's that can be processed with existing software and hardware systems.

2. Direct Detection of Hydrocarbons

Although many of the detailed geochemical processes and interactions are poorly understood, some general pathways of petroleum microseepage are known (McCulloch, 1973; Donovan, 1974a, b; Donovan, et al, 1974). The surface manifestations of these processes can be used empirically in the search for new oil and gas deposits and, given the proper conditions, they are amenable to remote detection.

An important adjunct to these processes that can be capitalized upon with the Landsat MSS system is a consequence of the localized reducing conditions in the near-surface and surface rocks resulting from the passage of hydrocarbons and/or their associated compounds. Reduction of ferric iron of iron-bearing minerals and dissolution and removal of the more soluble ferrous iron causes a discoloration (Donovan, 1974) that may be subtle to pronounced, depending in general upon the efficacy and rapidity of the leakage and the original color and iron content (and its oxidation state) of the altered rock. The spectral reflectivity of rocks is strongly influenced by the amount and oxidation state of iron (Goetz, et al, 1975). Alteration-controlling factors such as hydrocarbon dispersion and diffusion rates, the amounts and concentrations of organic compounds in the system at any given time, the influence of macro- and micrometerology, microbial interference, among others, are important but are at best, poorly understood details which may limit the suitability of Landsat analysis only to selected areas. This is primarily because the discolorations are usually most obvious in bedrock and aerial variation in the intensity of, and interferences with, the discoloration-causing processes, which may result in mottled effects with individual discoloration patches and streaks too small and variable for the resolving power of Landsat 1, 2, and C scanners. Landsat follow-on spatial resolution should help this problem, though aircraft data will continue to be necessary (≤ 3 meter resolution) to detect small-scale discolorations.

Research to date indicates that at least two fundamental patterns of alteration occur over structural or largely structurally controlled petroleum accumulations. (Alteration patterns over stratigraphic traps are known but their details have not yet been worked out.) Apical anomalies are those in which the surface and near-surface aerial distribution of alteration superposes closely over the main body of the accumulation at depth. Aureole surface anomalies occur as halos or rings peripheral to the vertical project of the accumulation. These kinds of patterns are known to geochemical explorationists both for minerals and petroleum. (For examples, see Sokolov, et al, 1971; Marmo, 1958; Armstrong and Hamsfro, 1973).

Feasibility studies have suggested the practicality of using Landsat data in certain areas to reconnoiter for the kinds of surface alterations described above. Given the resolution of the Landsat 1 and 2 system (approximately 80 m) broad apical anomalies would appear to be easier to delineate than narrow arcuate ones; however, research into this aspect is just beginning. Landsat follow-on should appreciably increase the number of such alteration patterns that can be detected, owing principally to its 30 meter resolution. Addition of the 1.5-1.8μm and 0.50-0.52 μm channels will aid in the discrimination of alteration products associated with hydrocarbon seepage.

B. PETROLEUM (OFF SHORE)

The previous section deals with petroleum exploration on land. Increasingly, however, exploration has been directed into offshore areas because of the potential of large undiscovered reserves. There are several offshore exploration problems that Landsat data can be helpful with, though most of these uses are just beginning to occur. The most rudimentary is ice flow and iceberg mapping, which is particularly important to the increasing petroleum exploration and tanker transportation in Arctic waters. Landsat 1 and 2 repetitive coverage would be useful for this purpose if newly collected Landsat images were available on a timely basis. By the time Landsat follow-on occurs, delivery time will hopefully be reduced to a few days after data collection. The thermal IR capability of Landsat C and follow-on should help somewhat in discriminating ice from snow and clouds.

Since seismic exploration in shallow shelf seas is commonly hampered by uncharted underwater obstructions, such as coral reefs and sand bars, Landsat imagery and computer-enhanced images can be of important use for bathymetric mapping. The addition of the 0.50-0.52 μm band on Landsat follow-on is expected to increase water penetration by approximately 30%. Hazards are not the only important features to be mapped in shallow seas, however. Sea bottom structural features (lineaments, salt domes, etc.) interpreted from Landsat data can lead seismic teams to likely regions of favorable structure for shallow petroleum deposits. Again, the new blue band of Landsat follow-on will be quite helpful, though the later time of day may be harmful in that more sunglint from normal sea state wave action may be expected.

Finally, it has been recently reported by at least one commercial firm and NASA that confirmed natural petroleum seeps have been detected from computer-processed Landsat 1 and 2 data. The major drawbacks from using current Landsat satellites for this purpose, however, are the poor spectral bands for oil slick detection, poor spatial resolution, and inaccurate geographical (latitude and longitude) data, especially on scenes with no land masses in them. Landsat follow-on should improve all of these problem areas, with the possible exception of geographical positioning. Unfortunately, Landsat follow-on will not be available until 1980.

C. COAL

A survey of some major U.S. coal companies indicates that the coal industry has generally been slow, to date, to utilize Landsat remote sensing in virtually any of its operation. State and Federal agencies have been in the forefront in investigating utilization of Landsat imagery in the areas of environmental and land-use considerations such as reclamation, revegetation surveys, mining inventorying, and strip mine monitoring.

In general, domestic exploration for coal has not operationally utilized Landsat imagery because U.S. coal deposits are known. Thus, industry's interest in remote sensing for coal deposits involves resource assessments, reserve determination, mine planning, geologic hazards evaluations, land inventorying, and reclamation and environmental surveys.

To accomplish these ends by remote sensing, the Coal Industry relies principally on periodic (1-6 month) low altitude (and to a lesser extent, high altitude) aerial photography from which useful 1:20,000 scale or larger scale maps can be simply derived for operational use. The principal improvement in the present Landsat (1, 2, and C) imagery which would encourage active utilization of Landsat remote sensing by the Coal Industry would be to significantly increase the resolution from which their operational maps are being derived. The planned 30 meter resolution of Landsat follow-on will undoubtedly encourage the Coal Industry's utilization of Landsat follow-on imagery in domestic coal operations.

Because of their domestic experience with aerial photography, U.S. international coal companies have generally not yet begun to utilize Landsat imagery in their overseas exploration efforts. Education of these companies as to the advantages of the utilization of Landsat imagery in poorly known overseas areas will probably enhance their utilization of present as well as planned Landsat remote sensing.

Some use may exist in a few overseas exploration programs. The principal reasons for the lack of coal exploration utilization of present Landsat imagery is that domestic coal deposits are relatively well known and that current industry utilization of remote sensing is largely limited to low and high altitude aerial photography from which large scale operational maps are produced.

Future exploration efforts utilizing present Landsat bands will probably include the 5/4 band ratioing to sense iron oxides associated with surface burned, "klinker" coal beds, especially in arid regions.

Currently the principal utilization of Landsat imagery for coal is by State Agencies and the Bureau of Mines. These agencies are experimenting with the initiating environmental and coal mine monitoring programs utilizing Landsat imagery (Ahmad and Dantner, 1975; Anderson and Schubert, 1976; Anderson, et al, 1975; Russell, et al, 1975; and Wobber, et al, 1975). The best bands for coal remote sensing for these purposes is Band 7 and, to a lesser extent, Band 5 for associated geological hazards studies (Ahmad and Dantner, 1975). The best results to date include Landsat analog and digital data applications (Anderson and Schubert, 1976) and ratioing of Bands 5/6 (Anderson, et al, 1975).

It is unlikely that the addition of the Thermal IR Band (10.5-12 μm) in Landsat C will significantly improve the current coal sensing capabilities of Landsat 1 and 2.

Anderson, et al (1975) cites a cost comparison between air photo and Landsat monitoring of surface mining areas per 10,000 square miles of $265-360 versus $0.30-0.60, a cost factor of 880/1 to 600/1 in favor of Landsat imagery.

For coal exploration, especially in remote, non-U.S. areas, Landsat follow-on will provide two significant improvements over Landsats 1, 2, and C capabilities which will strongly influence the coal industry's greater utilization of Landsat imagery. The primary improvement will be in the refinement of the resolution from 80 to 30 meters. The current 80 meter resolution is impractical for the detailed large scale maps derived from air photography which are currently operationally used by the industry. The improved resolution will benefit exploration by improving detailed geological mapping and by improving capabilities to interpret coal stratigraphy and structure.

A second major improvement will be the addition of the 1.55-1.75 μm band. This band can be ratioed with the shorter wavelength to better sense carbonaceous material, specifically coal, because of its high absorption compared to most other rocks and vegetation.

In terms of exploration, refined resolution to 10 meters would be of significant value to coal mapping capabilities and improve structural and stratigraphic interpretations. The same improvements mentioned above apply to improved capabilities for environmental, mine monitoring, and land use factors for coal.

D. SHALE OIL AND TAR SAND

The extensive deposits of oil shale and tar sands in Western U.S. and Canada could provide a potential future source of petroleum. Unfortunately, the current technology of extracting this valuable hydrocarbon source does not make it economically attractive at this time.

A survey of the major exploration companies which have current commitments toward research and development of this potential hydrocarbon resource indicates that Landsat data has not been utilized in their exploration program. This results from the fact that the extent of the deposits of oil shale and tar sands is currently well defined and sufficient to meet potential future demands.

When this hydrocarbon source becomes operationally and economically feasible, Landsat data will be invaluable in monitoring the environmental impact of the mining process, and Landsat follow-on, with its improved spatial resolution, will greatly increase our ability within this application area.

The General Electric Company conducted a limited investigation utilizing Landsat data of the Athbasca tar sands region, northern Alberta, Canada (Smith and Baker, 1976). Although their primary objective was to demonstrate the merits of the Image 100 processing system, their results for this specific application is significant in that digital processing and enhancement provided greater definition of the extent of surface outcrops of the tar sands than is currently known from published geologic maps.

E. GEOTHERMAL ENERGY RESOURCE EXPLORATION

The present Landsat system provides indirect evidence of geothermal resource areas manifested by volcanism, tectonism or high heat flow. The visible and near infrared bands, when ratioed, can be used to identify some hydrothermally altered areas. Landsat imagery is useful for locating fracture systems that allow hydrothermal fluids to circulate. It has potential for delineating geobotanical anomalies (e.g. vegetation-stressed areas) associated with surface temperatures, some of which are 2 °C or more, warmer over geothermal resource areas than over the surrounding terrain (Hochstein and Dickinson, 1970; Hodder et al, 1973). Aerial surveys of geothermal anomalies have outlined the extent of thermally active geothermal resource areas about as well as shallow ground surveys, and required only 6% of the time and cost (Dawson and Dickinson, 1970; Dickinson, 1975).

Some Landsat imagery examples of geothermal resource favorability have already been observed at known geothermal resource areas. Iron-rich alteration zones were found at Coso Springs, California, and a previously unknown linear fracture was located at Grass Valley, Nevada (Short, 1976). Large arcuate and linear fracture systems were located in association with thermally active areas in poorly mapped regions of Ethiopia (Hodder, 1975). Digital image processing is useful for enhancing these types of terrestrial anomalies (Rowan, et al, 1974; Goetz, et al, 1975).

Day-night temperature differences determined from 10.4 to 12.5 μm infrared radiation, measured twice daily on Landsat C and follow-on satellites, will be useful for thermal inertia studies (Pohn, et al, 1974; Watson, 1975; Kahle, et al, 1975). Thermal inertia maps outline contrasting features associated with the different physical characteristics of near-surface geologic materials (e.g. moisture content, density, specific heat, thermal conductivity). This provides a photo-geologic aid for locating faults and hydrothermally altered materials found in association with geothermal resources. Thermal inertia maps are not very sensitive to geothermal flux anomalies. Corrections for non-geothermal effects introduce uncertainties of about 300 HFU (equal to 12.6 W/m^2) based on two infrared measurements per day (Watson, 1974). Natural heat flows at geothermal areas larger than 1 km^2 range from 10 to 6000 HFU (White, 1965) whereas the world average for non-geothermal areas is 1.5 HFU.

Landsat nighttime thermal imagery is expected to outline the aerial extent and thermal energy patterns over geothermal areas with surface isotherms 1 or 2° C and 3 to 10° C or more above surface ambient. Some of these areas may contain exploitable concentrations of hydrothermal fluids at temperatures near 200° C and depths from 1/2 to 3 km. These hydrothermal fluids discharge along faults, fractures and channelways. This raises the local isotherms, increases the vertical temperature gradients and transfers heat partly by conduction, but mostly by convection to the surface (Horai and Uyeda, 1969).

Surface isotherms have been systematically contoured and compared with shallow vertical temperature gradient and heat flow measurements near Taupo, New Zealand (Dickinson, 1973; Dickinson, 1975) and Mt. Amiata, Italy (Hodder, et al, 1973). The 1 to 3° C above surface ambient infrared isotherms coincided with Taupo terrain where conductive heat flows over the upper 1 m layer of dry soil were 24 to 45 HFU. Infrared anomalies were 1° C and 2° C above surface ambient near Mt. Amiata where vertical temperature gradients were respectively 2 to 4° C/10 m and larger.

What is the meaning of this information and what importance may it have concerning geothermal resources? Near surface isotherms at Long Valley, California, a typical hot water resource system, have

significant patterns descriptive of the behavior of vertical temperature gradients to 30 and below to 300 meters (Lachenbruch,et al, 1976). Cool, warm and hot zones encompass regions from 1 to over 100 km^2 above areas where the dominant heat transfer processes have different features. At a depth of 10 meters, where both diurnal and seasonal temperature variations are small, the cool, warm and hot zones have typical isotherms at $9 \pm 1^\circ$ C, $13.5 \pm 1.5^\circ$C and $26 \pm 10^\circ$C; vertical gradients of 0 to 1, 2 to 4 and about 5 to 25° C per 10 meters; and conductive heat flows of 0 to 2 HFU, 4 to 8 HFU and 10 to 50 HFU. Based on average isotherms and temperature gradients at depths from 10 to 30 meters (extrapolated to the surface) and relative to the cooler ambient surface temperatures (along the periphery of the Long Valley caldera) warm zones would be 1 or 2° C above surface ambient over conductive regions above the reservoir and hot zones would be 3 to 10°C above surface ambient over reservoir discharge regions where horizontal and vertical circulation occurs at depths above 200 meters. This is consistent with infrared data (Hodder, 1976) and the behavior of the mean diurnal temperature above 1 meter (Le Schack, 1976). The localized cool zones are hydrologic recharge regions where ground water circulation has removed geothermal heat and transferred it to lower layers. These hydrothermal processes describe typical reservoir heat transfer characteristics for hot water resources, at temperatures near 200°C and at depths near 1 km (e.g. Long Valley).

During the day, solar heating variations are sometimes several degrees Celsius (e.g. over sunny and shaded areas of hillside topography). This has masked the effects of smaller regional geothermal temperature anomalies over the Geysers geothermal resource in California (Moxham, 1969; Siegal,et al, 1975). After the terrain has cooled, large area temperature or apparent temperature variations, over non-geothermal terrain, range from 0.2 to about 2°C (Del Grande, 1975; Del Grande and Cook, 1975). These are separable (from geothermal effects) by their varying aerial extent and shape conforming with the topography.

Better thermal resolution than is possible with Landsat C thermal imagery, from 10.4 to 12.5 μm, would be desirable to study major steam resources (e.g. the Geysers, California and Larderello, Italy). These geothermal resources have impermeable caprock, closed reservoirs and

natural heat flows less than 50 HFU. They are expected to have large area isotherms less than 1 $^\circ$C above surface ambient, that are hard to locate and characterize. Infrared imagery, sensitive to 3 to 5 μm radiation, has from two to three times better temperature responsivity (or thermal contrast) than imagery sensitive to 10.4 to 12.5 μm radiation. Temperature differences of 0.2 $\pm$ 0.1° C, over areas larger than 50,000 m^2 were found with 5 and 10 μm co-registered infrared data at two non-geothermal locations with different elevations at 290 and 370 meters above sea level. The temperature difference was mainly from the normal decrease at higher elevations modified by the effects of soil moisture and vegetation differences (Le Schack and Del Grande, 1976). Over previously unknown geothermal areas in New Zealand, 4.5 to 5.5 μm imagery was effective for identifying areas only 0.5 to 1.0° C warmer than the surrounding terrain. These areas, based on ground temperatures at 15 cm depths and lower to 1 m, were confirmed to be associated with geothermal heat (Dickinson, 1974). It would be useful to locate geothermal temperature differences from 0.2 to 1° C above surface ambient and isolate them from non-geothermal effects, based on their aerial extent and patterns. This is needed to study major geothermal systems like the Geysers with small regional surface temperature anomalies less than 1° C above ambient. By adding a second infrared band near 5 μm, on future satellites, it is believed this would be possible.

To summarize, Landsat C and follow-on satellites will provide a useful method for locating indications of geothermal resource favorability. It will provide a photogeologic aid for distinguishing surface alteration, faults, large linear fractures and anomalous heat. Nighttime thermal imagery will outline the extent and thermal energy patterns associated with some but not all geothermal resources. Typical hot water reservoir systems with favorable commercial potential generate large area surface isotherms 1 or 2° C and up to 10° C or more above ambient for nearby regions. These isotherms have been distinguished from non-geothermal effects with nighttime imagery. Their patterns sometimes describe the behavior of deep hydrothermal processes associated with the resource. Some notable dry steam reservoir systems (e.g. the Geysers, California) are expected to have large area isotherms less than 1° C above surface above surface ambient. The thermal resolution features of the existing Landsat C infrared system are not sufficient to resolve thermal anomalies

of this magnitude. To do so would require the addition of an infrared band, near 5 μm, with better thermal contrast.

TABLE III-1
SATELLITE EVALUATIONS FOR ENERGY RESOURCES EXPLORATION

Good (Neutral) Detrimental

3 2 1 0 -1 -2 -3

	Petroleum On Shore	Coal	Shale Oil Tar Sand	Geothermal	Petroleum Off Shore	Average						
LANDSAT 1 and 2												
80 m Spatial Resolution	2	1	1	2	2	1.6						
Signal/Noise - Moderate	0	1	1	-1	0	0.2						
Spectral Range 0.5 - 1.1 μm	2	1	-	0	2	0.2						
Repeat Coverage	2	1	3	3	3	1.4						
182 x 182 km mi. Format	3	1	1	0	3	1.6						
Mid-morning 9:30 a.m.	3	2	2	0	3	2.0						
Digital Tapes - Raw data	2	2	3	2	1	2.0						
* Data Delivery as presently experienced	-1	0	-3	-1	-3	-1.6						
* Image Quality as presently available	-3	-1	-1	-3	-3	-2.2						
Incidental Stereo	0	-2	0	-1	-1	-0.8						
Geometry - Excellent	3	2	2	3	3	2.6						
LANDSAT C												
Add: 10.4 to 12.5 μm	1	0	0	3	3	1.4						
* Digital Tapes, Corrected	0	2	2	3	0	1.0						
* Data Delivery, Rapid (48 hr.)	1	2	3	3	3	2.8						
RBV Panchromatic	0	2	0	3	0	1.0						
LANDSAT FOLLOW-ON												
30 m Resolution (except thermal)	3	2	3	3	3	2.8						
Add: Blue Band (water penetration)	1	0	0	2	3	1.2						
Add: Near IR (1.6 μm - mineral)	1	2	1	3	0	1.4						
Program Continuity	3	3	3	2	3	2.6						
Near-Noon - 11:00 a.m.	-2	0	2	0	-2	0.0						
Signal/Noise - Improved	2	2	3	3	2	2.4						
Geometry - Degraded at lower altitude	-3	2	0	0	-3	0.8						
10.4 - 12.5 μm Day-Night coverage												
Resolution - better than 30 m	2	3	3	0	3	2.2						
Additional Spectral Bands												
Passive Microwave	0	0	0	2	3	1.0						
Radar	2	0	0	1	3	1.2						
Laser Topog. Profile	0	0	0	1	2	0.6						
Fraunhoffer Line Discrim.	2	0	2	2	0	1.2						
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	0	3	2	3	0	1.6						
8.2 - 9.4 μm (with 10 - 12 μm)	0	0	2	3	0	1.0						
Different Variable Time of Day												
Very low sun angle	3	3	0	1	3	2.0						
Night (for thermal IR)	3	0	2	3	3	2.2						
Non-Sun synchronous	0	3	0	-3	-	0.0						
Day + Night IR (Max T)												
Stereo Coverage - complete w/vert. exag.	3	3	0	2	2	2.0						
* Additional Pre-processing of digital data												

* = Ground Station Function

CHAPTER IV

ENVIRONMENTAL GEOLOGY

This section is addressed to the application of Landsat follow-on to the selection and evaluation of sites for engineered structures in terms of geologic hazards, earth materials for engineering usage and environmental impact (exclusive of mineral and mineral fuel extraction). Remote sensing data are typically used in site investigations for dams, power plants, flood control structures, towns, airfields, bridges, tunnel locations and high-rise buildings. These data are also applied to corridor surveys for highways, railways, canals, pipelines and powerlines, as well as in exploration for stone and aggregate and fill material.

Data from Landsat follow-on Thematic Mapper (TM) and multispectral scanner (MSS) will be useful primarily in the planning stages of geotechnical investigations performed in conjunction with major construction projects. These data will also be of use in post construction monitoring of certain projects.

The general factors considered during the planning stages of civil works type projects include (1) a regional analysis of natural and cultural resources to develop the scope of the project, (2) the preliminary siting of project components, (3) the development of an environmental impact statement and (4) the generation of a preliminary design for the development of a cost/benefit analysis for the project.

The synoptic view of the project region available from Landsat follow-on will depict conditions existing at a given time and indicate relationships between climate, geology and cultural factors that are of particular value in evaluating the impact of a new engineering facility on the environment. Additionally, evaluation of sequential coverage of the Landsat follow-on will provide a method for noting changes in the landscape and its environment, and the system's greater resolution capabilities will be an improvement over the present MSS system in Landsat 1 and 2 for numerous applications. Examples of some of these applications include linear delineation, landform analysis, rock and soil identification, and recognition of potential hazards, such as landslides and sinkholes. The greater spectral range of the TM will permit better discrimination of soil and rock types and vegetation cover. The 9-day coverage frequency of Landsat follow-on data to environmental geology are summarized in the accompanying table, and a number of these applications are documented in the following paragraphs.

A. EARTHQUAKE DAMAGE

Both active and inactive faults present potential hazards for engineered structures. During earthquakes, structures astride the fau trace are subject to rupture, and structures within the area of significant ground shaking are affected by ground acceleration and secondary ground failures associated with the ground shaking (liquefaction, landslides, lateral spreading, soil collapse). Inactive faults present a hazard to certain structures, such as dams, because fault breccia zones are generally highly permeable to fluids moving parallel to the fault.

An active fault is one capable of generating a damaging earthquake. Faults that have moved during historic or Holocene (past 11,000 years) time are considered active. The historic earthquake record dates back only about 200 years. Earlier fault activity must be identified by stratigraphic evidence, or in arid regions where landforms persist for thousands of years, by geomorphic indicators of fault displacement. These include scarps, offset drainage, truncated ridges and depressions. Fault blockage of ground water in alluvium may be manifested in vegetation differences across active faults. Many of these indicators are identifiab in arid areas at a spatial resolution of 10-30 m (Merifield and Lamar, 1975). Figure IV-1 shows a segment of the active Garlock fault as seen fr Skylab, in which a number of indicators of recent movement are clearly identifiable. Except for a few very large faults, these geomorphic indicators are not identifiable in Landsat 1 and 2 imagery. So while faults may be recognizable on Landsat 1 and 2, it cannot be determined if they are active. Larger scale imagery, or better spatial resolution is required to make this important distinction. For example, this distinction is critical to understanding the plate tectonic processes in the Himalayan Region (Molnar and Tapponnier, 1975). Because of its improved resolution, Landsat follow-on will permit the identification of many faults capable of generating damaging earthquakes in areas where limited aerial photo coverage is available; e.g., Asia Minor, Central and South America.

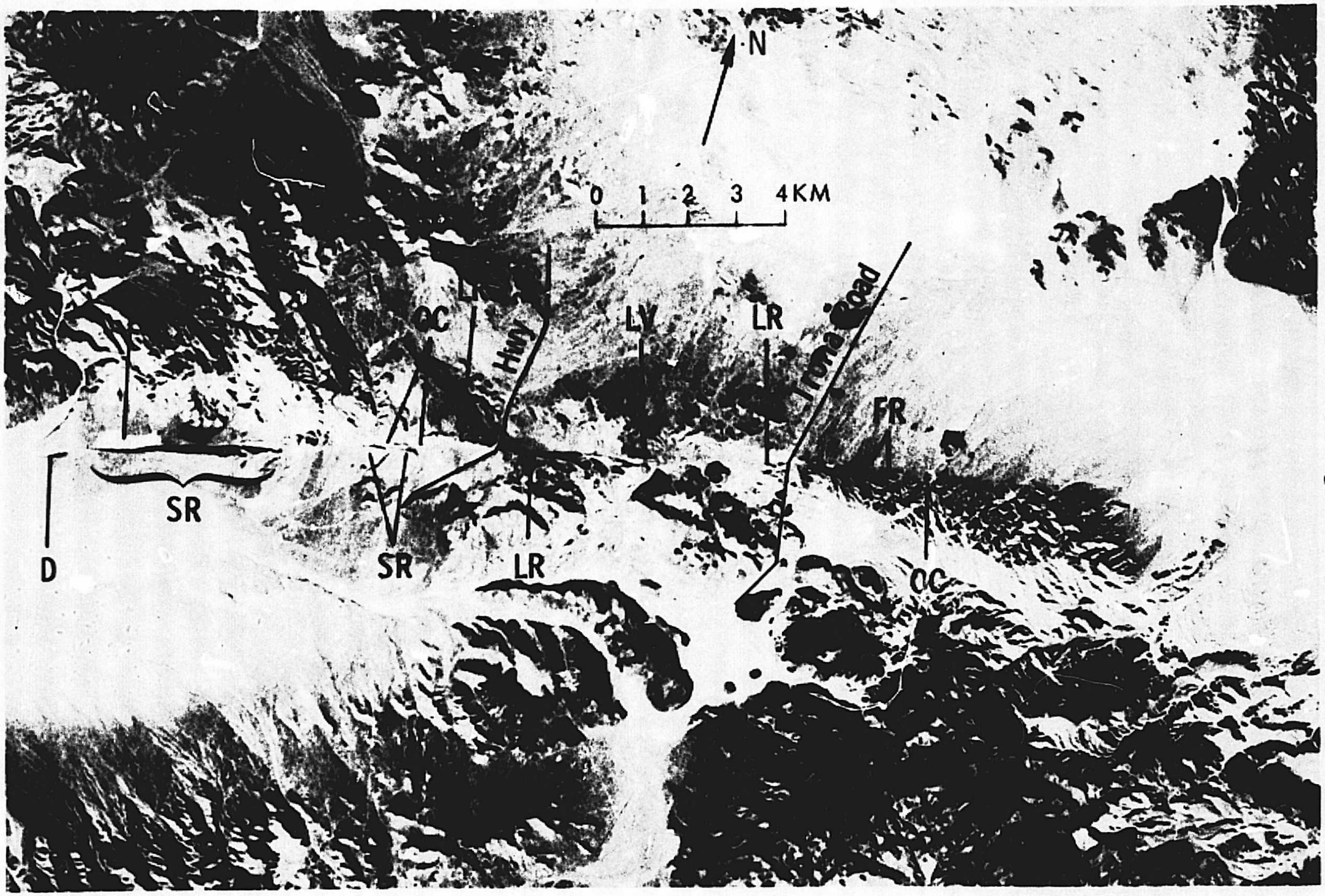


Figure IV-1. Section of Garlock fault south of Ridgecrest, California. Enlargement of a portion of Skylab 4, 190B camera, Roll 92, Frame 347 (original in natural color). Legend: D, depression; SR, shutter ridge; OC, offset channel; LR, linear ridge; LV, linear valley; FR, faceted ridges.

In contrast to the great potential for locating possible active fault zones by remote sensing techniques in the arid United States, location in the eastern United States is one or two levels more difficult. Location is hindered by the thick soil and vegetation cover, and by the generally lower level of seismicity. Ground investigations have revealed several small post-Cretaceous faults, some of which may be as young as Holocene. These do not appear prominently on Landsat 1 and 2 imagery; however, the higher resolution of the Landsat follow-on might permit better identification of possible fault zones through the recognition of aligned vegetation and land use patterns, and anomalous land use patterns resulting in identifiable lineaments.

Cross-strike lineaments may be identified with seismicity in some parts of the eastern United States. Landsat 1 and 2 images are currently being analyzed with respect to cross-strike linears throughout the eastern seaboard, and possible correlations with seismicity noted. Landsat follow-on images will improve these analyses because of the better resolution; however, the higher sun angles will be detrimental. The thermal IR on Landsat follow-on may provide another tool for identifying and documenting these cross-strike features. The preparation of regional fracture-lineament maps to accompany the growing number of regional seismic networks throughout the United States is an important step in consideration of nuclear power plant siting.

B. LANDSLIDES

Monitoring landslides is one of the more significant potential applications of earth-orbiting satellites in the earth sciences because earth movements are one geologic process which proceeds on a relatively short time base. Little use has been made of Landsat 1 and 2 in the direct identification of landslides because the 80m resolution is insufficient. Improvement to 30m resolution with Landsat follow-on should permit larger landslides to be identified; however, the vast majority of landslides are much smaller and will still be below the resolution limit. The planned higher sun angle and lack of stereo are also detrimental to landslide identification.

Figure IV-2 is a portion of a landslide map prepared by the U. S. Geological Survey for part of eastern Ohio and shows the level of detail of some current investigations. Some use of Landsat follow-on could be made to identify larger landslides and to locate trends along which unstable ground may be concentrated. Ideal exploitation of repetitive satellite coverage for this application requires better resolution, however.

C. SUBSIDENCE AND CAVE-INS

The hazard of cave-ins and sinks in limestone terrain has been identified in Georgia by observing alignments of the larger sink holes on Landsat 1 and 2 images (S. Pickering, Georgia Dept. of Natural Resources, personal communication). Knowledge of the areas where limestone sinks were most likly to be encountered permitted significant savings in highway construction. Landsat follow-on, by permitting smaller sinks to be identified, will sharpen the ability to predict sink hole hazards.

Subsidence due to withdrawal of underground water is a continuing problem over much of the Gulf Coastal Plain. Linears along which recent movement has occurred have orientations which vary with their scale. Landsat follow-on data which will supply a synoptic view at improved resolution should help in mapping these hazards.

D. VOLCANIC ERUPTIONS

The hazard from volcanic eruptions is one that is typically monitored at a variety of scales from ground observations to satellite reconnaissance. The greatest value from satellite observations is in remote areas. For example, Landsat monitoring of Iceland has revealed the potential to quickly map new flows and tephra falls. One of the hazards from the latter has been livestock poisoning from a 1970 eruption which might have been prevented had Landsat imagery been available (Williams, et al, 1974). Another application related to volcanic monitoring is to prepare a budget of particulate matter added to the atmosphere and assess the impact of this activity on global climatic patterns.

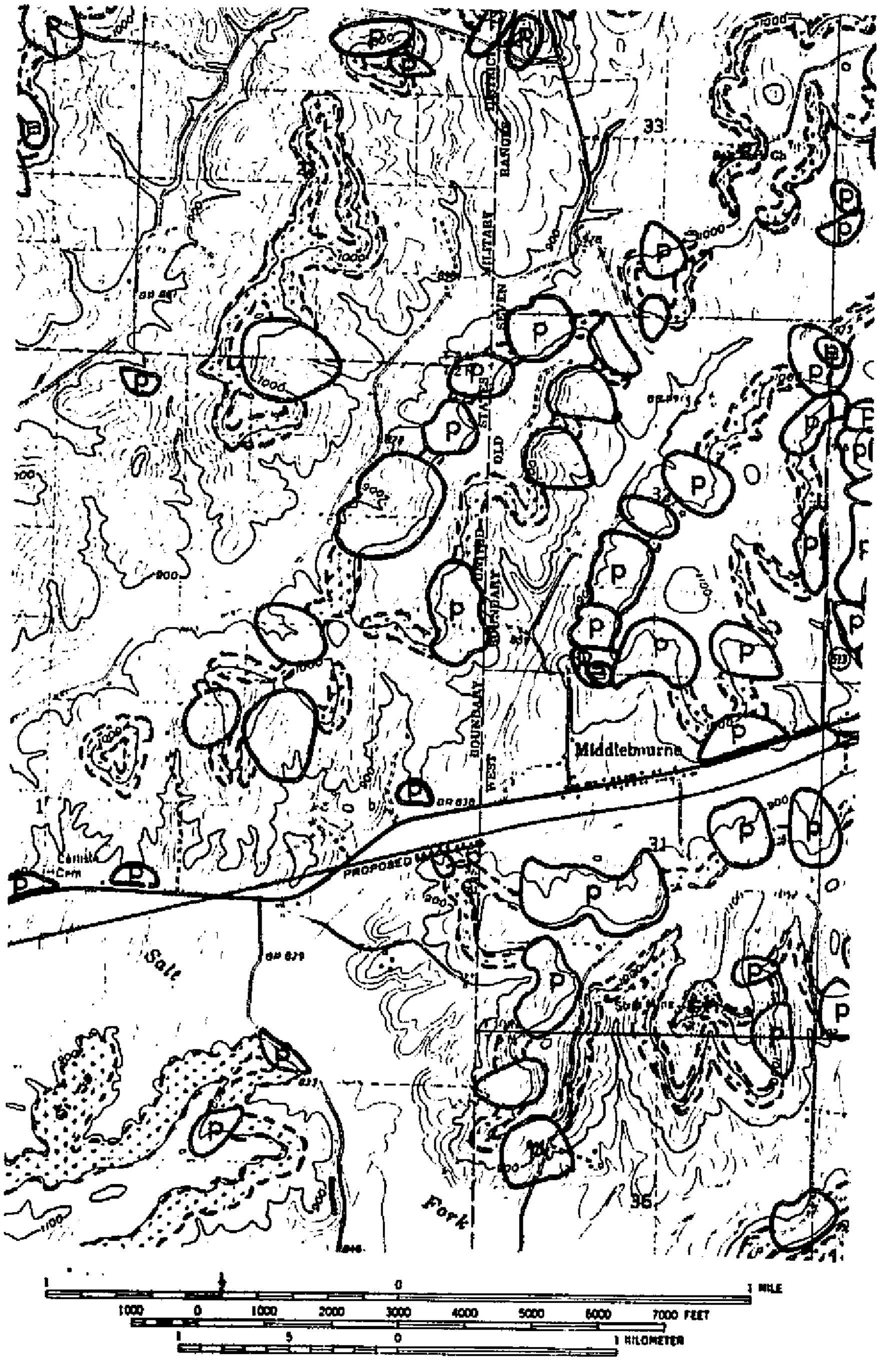


Figure IV-2. Portion of a landslide and disturbed ground map for the antrim quadrangle, Ohio (Davies, Ohlmacher and Fox, 1976). Legend: a, active and recent slides; p, prehistoric slides; open, coves with clay slabs; dashes, rock and soil susceptible to slides. Larger prehistoric slides and coves should be visible on Landsat follow-on thematic mapper imagery.

E. FOUNDATION AND CONSTRUCTION MATERIALS

The physical properties characterizing a foundation material are dictated by the composition, degree of consolidation and structure (e.g., the presence or absence of planes of weakness). The occurrence of construction materials (quarry rock, sand and gravel, and clay binders) is closely related to associated landforms. Landform analysis, therefore, is the commonly used approach to the search for construction materials; examples are alluvial deposits (sand and gravel), sand dunes (sand), residual deposits (lag gravels and cinder cones).

Although large-scale color photography has been noted to be best for the location of construction materials, the close relationship of material type to associated landforms provides the opportunity for the use of Landsat follow-on for this purpose. In a material survey performed by a team of scientists over a region in the Mississippi Delta (Orr and Quick, 1971), it was noted that photoindex sheets and radar imagery proved useful in performing a regional analysis - e.g., determining the physiographic setting and identifying the Landforms with material association. In a corollary evaluation in this study, it was also noted that many of the landforms associated with contruction materials could be distinguished on an Apollo satellite photograph of the area (Rib, 1975, p. 1887).

The discrimination of alluvial deposits in arid regions is aided by manipulation of spectral data. The ratio of Landsat Band 5 to Band 4 was found to be particularly useful in separating alluvial soils of different maturity (and, therefore, different iron-oxide content) in the western Mojave desert (Merifield, et al., 1975). Improved identification and discrimination of surficial materials from Landsat follow-on seems likely; there is a need, however, for additional research on the utility of the 1.6μm and 10-12μm bands for this purpose.

F. COST BENEFITS

Available data do not make possible a definitive evaluation of the cost benefits that can be realized from utilization of Landsat follow-on data. Toward this goal, however, a recent study exemplified

the losses associated with geologic hazards in California (Alford, *et al*., 1973). Losses in property damage, life and mineral resources from geologic hazards in California are estimated to be $55 billion for the period 1970-2000. An estimated $38 billion of this could be saved by application of current state-of-the-art reduction measures at a cost of $6 billion. Foreseeable advances in the state-of-the-art loss reduction measures could result in near-zero loss of life and a 90 percent reduction in property damage. Landsat follow-on data can reasonably be expected to play a significant role (conservative -- 1%) in this reduction because of its ready availability, frequency of coverage, and low cost to the user.

TABLE IV-1
SATELLITE EVALUATIONS FOR ENVIRONMENTAL GEOLOGY

Good (Neutral) Detrimental
3 2 1 0 -1 -2 -3

	Earthquake Damage	Landslides	Subsidence and Cave-ins	Volcanic Eruptions	Foundation and Construction Materials	Earth Moving	Subsurface Water	Drainage and Erosion	Environmental Impact of Grading	Average	
LANDSAT 1 and 2											
80 m Spatial Resolution	-2	2	-1	3	1	0	2	2	-1	0.7	
Signal/Noise - Moderate	-1	-3	-3	-1	-3	-3	-3	-3	-3	-2.6	
Spectral Range 0.5 - 1.1 μm	-1	-2	-3	-1	-1	-3	-3	-3	-3	-2.2	
Repeat Coverage	0	2	2	3	1	0	0	0	0	1.1	
182 x 182 km mi. Format	3	1	0	2	0	0	0	0	0	0.7	
Mid-morning 9:30 a.m.	2	3	2	0	-1	2	1	2	2	1.4	
Digital Tapes - Raw data	3	1	2	1	3	2	2	2	2	2.0	
* Data Delivery as presently experienced	0	-3	0	-3	0	0	0	0	-3	-1.0	
* Image Quality as presently available	-1	-3	-3	-2	-1	-3	-3	-3	-3	-2.4	
Incidental Stereo	-2	-3	-2	0	0	-3	0	-3	-2	-1.7	
Geometry - Excellent	1	0	3	0	0	3	3	3	3	1.8	
LANDSAT C											
Add: 10.4 to 12.5 μm	1	0	0	0	1	0	0	0	0	0.2	
* Digital Tapes, Corrected	2	2	3	0	3	3	3	3	3	2.4	
* Data Delivery, Rapid (48 hr.)	1	3	0	3	0	0	0	0	3	1.1	
RBV Panchromatic	2	2	3	1	2	3	3	3	3	2.4	
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	2	2	2	2	2	2	2	2	2	2.0	
Add: Blue Band (water penetration)	0	0	0	0	1	0	0	0	0	0.1	
Add: Near IR (1.6 μm - mineral)	0	0	0	3	3	2	0	0	0	0.9	
Program Continuity	0	2	3	3	0	0	3	3	3	1.9	
Near-Noon - 11:00 a.m.	-2	-2	-3	0	1	-3	-3	-3	0	-1.7	
Signal/Noise - Improved	2	2	3	2	2	3	3	3	3	2.6	
Geometry - Degraded at lower altitude	-1	-1	-3	-1	-1	-3	-3	-3	-3	-2.1	
10.4 - 12.5 μm Day-Night coverage	1	1	3	1	1	3	3	3	3	2.1	
Resolution - better than 30 m	3	3	3	2	2	3	3	3	3	2.8	
Additional Spectral Bands											
Passive Microwave	0	0	0	0	0	0	2	0	0	0.2	
Radar	3	2	3	1	2	3	1	3	3	2.3	
Las.r Topog. Profile	1	0	0	3	0	0	0	3	0	0.8	
Fraunhoffer Line Discrim.	0	0	0	0	0	0	0	0	0	0.0	
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	0	0	0	2	2	1	0	0	0	0.6	
8.2 - 9.4 μm (with 10 - 12 μm)	0	2	2	2	2	0	2	2	0	1.3	
Different Variable Time of Day											
Very low sun angle	3	2	3	-2	1	3	3	3	3	2.1	
Night (for thermal IR)	2	3	3	0	2	1	3	3	0	1.9	
Non-Sun synchronous	2	2	3	0	1	3	3	3	3	2.2	
Day + Night IR (Max T)	2	3	3	3	2	2	3	3	3	2.7	
Stereo Coverage - complete w/vert. exag.	3	2	3	2	1	3	1	1	3	2.1	
* Additional Pre-processing of digital data											

* = Ground Station Function

TABLE IV-2
APPLICATION ASSESSMENT TABLE

Application:

Description of Environmental Geology Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Drainage and Soil Erosion		
Topographic drainage system.	Regional pattern of streams, ridges.	Major topographic features are detectable. For engineering action, Landsat imagery is below useful threshold of discrimination.	Greater detail (resolution, discrimination) will help.
Poorly consolidated surficial units ("erodability")	Porosity: thermal inertia. Pore-water content: vegetation or moisture content variables.	Units of major extent, with appropriate "signatures" OK. State-of-the-art is at threshold of capability.	Test cases are needed to confirm ground truth as to image signatures denoting porosity.
Areas of past or present sedimentation - natural - construction-related	Fans, deltas; sedimentary plumes; sediment load in streams; filling of reservoirs, lakes.	Major features only -- most real problem areas are too small to detect, let alone evaluate.	More detail in imagery will help. Water-penetrating bands will help. Specialized enhancement techniques should help.
	Shoreline Erosion		
Beach areas -- changes over time.	Repeated images of land/sea boundary.	Major changes are detectable and measurable; most of the real cases are below the threshold of detection except over multi-year periods.	Local on-site detection and low altitude aerial photos are required for any useful evaluation or planning remedial action.
Retreating cliffs.	Down current plumes.		Water-penetrating bands.
Landsliding along coastal cliffs.	Down current plumes.		
"Saved" areas at erosion-control structures.	Down current plumes.		Corps of Engineers has information.
	Earthquake Damage		
Location of Active Faults.	Linears - topographic indicators of recent movement (scarps, offset drainage, groundwater barriers).	Good, for location of major faults. Indications of recent movement identifiable in arid to semi-arid regions for large faults.	
	Seismicity.	No.	DCP only.
Areas subject to excessive shaking or ground failure.	Regional soil mapping, position of groundwater table, unstable slopes.	Same as Landslides and Subsurface water.	
Unconsolidated or water-saturated surficial units (e.g., basin sediments, shoreline fill).	Porosity of soil or rock units. Depth of water table.		
	Subsurface Water		
Elevation of water table. Moisture content of soils.	Springs and seepage areas; lake bottom springs; Phreatophytes; thermal inertia reflects moisture. Seasonal variability significant.	Recognizable in arid regions.	Need wave lengths to penetrate surface units.

TABLE IV-2 (Cont'd)
APPLICATION ASSESSMENT TABLE

Application:

Description of Environmental Geology Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters")	Remarks (evidence experience problems, etc.)
	Subsurface Water (Cont'd)		
		Large water bodies detectable, but not small ones.	
		Minor, but significant, variables in soil moisture mostly below threshold of detection.	Need more detail as possible.
Location of aquifers and their significance.	Distinguish sand-and-gravel from clays: thermal inertia. Distinguish buried channels in glacial areas.		Thermal inertia signatures need to be refined.
Location of aquicludes and their effectiveness.	Faults: (see discussion on "Earthquake Hazards").	Large or long linear features detectable. Most too small.	Need all possible resolution discrimination.
	Impermeable rock formations: thermal inertia.		
Direction of groundwater migration (to predict, monitor pollution).	Thermal plumes reveal lake-bottom springs.	Detectable only if major.	If possible to detect "tagged" or polluted water it would help.
	Vegetation distribution (phreatophytes; possibly distressed by pollutants).	Detectable only if major.	
	Biologic content -- oxygen, algae.	Chlorophyll content very detectable.	Water-penetrating band will help.
	Foundation and Construction Materials		
Physical properties of rock and soil (bearing capacity, shear strength, planes of weakness, porosity, permeability, grain size.	Landform, color, associated vegetation, bedding and jointing, drainage pattern.	Differentiation of soil and rock type demonstrated in arid to semi-arid regions. Identifications to some degree by landford, drainage pattern, vegetation and spectral response.	
	Volcanic Eruptions		
Active volcanoes and distribution of new volcanic products which may pose hazards to agriculture or works of man.	Flows and tephra mantles.	Feasible because of distinct appearance of new volcanic products showing lack of vegetation and special spectral properties.	Has particular applicability to remote areas.
	Landslides		
Prehistoric slides which can be reactivated by excavation or leading.	Topographic expression: hummocky topography, up slope scarps.	Feasible for larger slides (71 km across) after comparison with low altitude views.	Nested 10 m resolution and stereo coverage would greatly aid feasibility.

TABLE IV-2 (Cont'd)
APPLICATION ASSESSMENT TABLE

Application:

Description of Environmental Geology Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Landslides (Cont'd)		
Areas that may be susceptible to sliding or instability.	Geologic factors which may localize or lead to unstable ground: specific geologic formations or structural features.	Feasible where formations and structures can be identified and mapped. Linears readily mappable and may localize landslides; formations mappable only in favorable situations.	Knowledge of relation of linears to landslide occurrence.
Active and recent slides on which ground is unstable and subject to extensive sliding if disturbed.	Topographic expression: hummocky topography, scars, toes of slides. Disruption of groundwater flow as indicated by soil and vegetative differences.	Feasible for larger slides (more than 1 km across) after comparison with low altitude views. Feasible where groundwater effect appears in visible and thermal infrared images.	Nested 10 m resolution for use in selected areas would greatly aid feasibility. Need quantitative studies on relation of infrared images.
	Parameters to be measured on a repetitive basis, data to be available within short time frame.	Nine-day coverage allows proper monitoring of slide activity; data flow allows timely updating.	Stereo would allow more confident identification.
	Subsidence (Regional)		
Lowered elevations, encroachment of sea, lakes.		Poor: vertical displacement too minor and widespread for Landsat detection.	Local observation will always be quicker and very quantitative.
Subsidence cracks visible on surface.	Vegetation moisture discontinuities. Curved linears.	Most subsidence cracks are below detectable threshold.	Local observation will always be quicker and very quantitative.
Altered water gradient (canals).	None.	Not detectable until condition has gone to disaster.	Local observation will always be quicker and very quantitative.
	Differential Settling (Local)		
Structural stress (dams, airports, transportation lines).	None.	Very poor: too local, too minor for Landsat.	Local observation sooner, more accurate.
Poorly consolidated, porous surficial units.	Porosity indicated by vegetation, moisture discontinuities. Possibly thermal inertia.	Probably threshold of detection. "Signatures" still need to be developed, if possible.	Research needed to correlate ground truth in potential settling-prone areas, to match enhanced image discontinuities.
Hydrocompaction areas: very porous fan sediments in desert areas.	Porosity revealed in thermal inertia signature.		
	Cave-Ins (Mines; Underground Excavations)		
Surface cracking.	Vegetation, moisture discontinuity.	Very poor: too local, too little magnitude for Landsat	Local observation always faster, surer -- and needed anyway.

TABLE IV-2 (Cont'd)
APPLICATION ASSESSMENT TABLE

Application:

Description of Environmental Geology Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Cave-ins (Mines; Underground Excavations) (Cont'd)		
Faults, joints intersect mine workings, tunnel routes	Linears.	Major linears: excellent for minor shear zones, joints below detection threshold are still dangerous. Detection capability better than evaluation capability.	U. S. Bureau of Mines reports very useful. By knowing major linear systems, ground research is enhanced. Will always need "in the tunnel" detail.
Limestone (Karst) topography.	Distinctive topographic "signature". Linears, alignments of sink holes.	Detection of regional karst and major lineaments OK. Local problems too small to see.	Corps of Engineers reports very successful work on sink holes.
	Earth-moving Properties		
Degree of consolidation induration, hardness (solid rock vs. unconsolidated material).	Thermal inertia signature. Vegetation (indicative of porosity).	On regional scale: good. On local detail: no good.	Need wavelength that penetrates. On-site examination necessary in every case. - how much cost to excavate?
Number, spacing and direction of joints, fractures.	Linears (swarms or broad and shatter zones).	Major linears, which are detectable, are not very useful. Swarms and "insignificant" joints and fractures aren't detectable.	Any increase in discrimination resolution would help. - will banks hold if excavated? - would tunnelling costs be excessive?
Porosity.	Vegetation.		- how amenable to strengthening by soil cement, grouting, etc.
	Environmental Impact of Engineering Structures		
Disruption of the land surface, stripping of vegetation, disruption of normal drainage and sediment transport systems, air and water pollution, vegetation stress	Landforms, drainage patterns vegetation health, sediment plumes, algae blooms, particulate matter in air.	Treated elsewhere in this report?	

CHAPTER V

MAPPING AND INTERPRETATION

This section provides an assessment of the proposed Landsat follow-on system for geologic mapping and interpretation. In this context, geologic mapping and interpretation is used in the broadest sense of the term. It includes all mapping of the geometry and composition of the earth's surface materials, i.e., lithologic and structural mapping (the two basic facets of the standard geologic map), as well as special purpose mapping, such as geomorphic (landform) maps, surficial deposits maps, etc. Also included in this context is planimetric base mapping, since the geologic information must be plotted on an adequate base, and since Landsat imagery itself has proven to be a near-perfect Orthophoto base map medium for this purpose.

The importance of geologic mapping and interpretation for mineral and petroleum exploration (and hazards/engineering or environmental geology) cannot be overstated. The geologic map provides the data base from which the fundamental interpretations are made to reconstruct the chronology of geologic events affecting a region. Then, and only then, can a comprehensive and efficient exploration program (or hazards assessment) be effectively carried out.

Mapping is required at levels of detail directly related to the detail of exploration or environmental study, i.e., very detailed mapping for selection of drill or mine sites, and delineation of site hazards, more general to select areas for seismic work, sampling or soils studies, regional to identify petroleum provinces or mineral-rich areas and continental for assessing potential for rich resource areas and development of theories of petroleum accumulation and metallogeny.

These changes of Landsat follow-on will change the capability of the satellite as a tool for 1) making orthophoto maps, and for mapping 2) rock types, 3) geomorphic features, 4) structures other than linears, 5) linears and long lineaments, 6) circular features, and 7) Arctic sea ice. These changes in capability will be discussed in order, followed by a strong case for stereo coverage in a specially designed satellite.

Generally speaking, the overall quality of the geologic maps that can be produced using Landsat follow-on imagery will be significantly improved, principally as a result of the three-fold increase in spatial resolution of the Thematic Mapper. For instance, 75 m resolution permits accurate mapping at the scale of 1:250,000. On the other hand, the reduction in shadows will reduce the ability to interpret surface morphologic features. Increased radiometric data will also assist in all applications, but distortions, both radiometric and geometric, caused by the wider angle of instantaneous "view" of the sensors, will adversely affect many applications to an unknown degree.

A. ORTHOPHOTO MAP PREPARATION

A very useful product of Landsat 1 is the Orthophoto map, a number of which are already available as Federal and State publications. These are printed halftone reproductions of Landsat mosaics of individual states or smaller regions. They may be monochromatic, made from a single spectral band, or polychromatic (false color) combinations of two or three bands. They are "photographic" renditions of landscape reality rather than man made maps, and as such are extremely useful in regional structural analysis. Cultural information is easily overprinted on these maps.

Such maps are becoming widely used, and will probably replace current road maps, aeronautical charts, and inland and coastal navigation charts because of their graphic representation of landforms and cultural features.

The resolution of present Landsat imagery falls short of the 75 m required to produce maps at 1:250,000 scale whose internal positional accuracy meets National Map Accuracy Standards. Accordingly, Landsat orthophotomaps are now made at 1:500,000 scale. With a resolution of 30 m, however, accurate orthophotomaps could be made at 1:100,000 scale. As such, they could perhaps be used instead of the green overprint on 1:62,500 and smaller scale topographic maps published by the U.S. Geological Survey.

B. MAPPING ROCK TYPES

1. Addition of the MSS band 1.55-1.75 μm in the "Thematic Mapper"

In the region of 1.6 μm there is a greater range of intrinsic reflectance for surface materials than at any other wavelengths in the 0.4-2.5 μm range. With the exception of playa materials, reflectance values of surface materials in the 1.6 μm band range from 10 to 75% versus 8 to 40% in the present Landsat spectral bands.

Vegetation reflectances in the 1.6 μm region vary greatly depending on the water content of the foliage. Green vegetation generally has a low reflectance (<20%) while many rocks have a high reflectance (>30%) in this region. On the other hand, in bands 6 and 7 of Landsat 1 & 2 the reverse is true. The reflected solar energy received by the spacecraft is weighted according to the relative coverage of vegetation and soil as well as the relative reflectances of the materials. This property leads to a predominance of the vegetation signature in bands 6 and 7 in Landsat 1 & 2 for aerial coverage greater than 40%, but in the Thematic Mapper the 1.6 μm band will exhibit a predominance of the rock signature even when the vegetation aerial coverage is 50%.

Seen from the geobotanical point of view, the 1.6 μm band will provide a unique capability for measuring vegetation stress by reflecting the underlying soil composition in addition to other factors.

Field spectral measurements made in and around areas of hydrothermal alteration taken mainly of igneous rocks and their alteration products have been analyzed by statistical techniques. The method of linear discriminant analysis was applied to the data split into 26 discrete bands of 0.05 μm width in the 0.4-1.0 μm region and 0.1 μm width in the 1.0-2.5 μm region. When the analysis was applied to 10 classes of materials including basalts, limestones, altered materials and others, the 1.6 μm band showed to be the most important band for separation of these classes.

The second most important band usually fell in the 2.2 or 1.3 μm region. The 2.2 μm region is particularly important for providing information pertaining to hydrous rocks. The lack of a 2 - 2.4 μm band on the Thematic Mapper will have the consequence that (1) limonitic (or hermatitic), but anhydrous unaltered rocks, such as ferruginous sandstone and tuff, will not be distinguishable from limonitic altered rocks, and

(2) unaltered anhydrous rocks that are highly reflective in the 1.6 region will appear similar to iron-poor hydrous altered rocks. Thus, a problem of major economic importance which has already been encountered with Landsats 1 & 2, namely the poor ability to separate iron oxides associated with mineralization from more common iron oxides associated with mineralization from more common iron oxide occurrences, will remain unsolved.

Additional support for the importance of the 2.2 μm band comes from analysis of S 192 spectral radiance data by Marrs and his associates, concerning sedimentary rocks in Wyoming. Of the visible and near-infrared spectral bands, contrast among the units was found to be highest in the 2.2 μm band, although contrast was also high in the 1.6 μm region. This observation is consistent with the presence of hydrous (shale), anhydrous (sandstone) and carbonate (limestone and dolomite) rocks in the sedimentary sequence.

In general, the addition of the 1.6 μm band will provide a significant increase in information relevant to geologic applications over Landsat 1 & 2. Also, the increased signal-to-noise ratio, providing 256 gray levels instead of 64, will allow subtle tonal features associated with facies changes of all kinds to be displayed. Since only 64 gray levels, at most, can be displayed at one time on film, digital processing will be mandatory.

2. Addition of the 10-12 μm Thermal Infrared Band

This will be most useful for geologic applications, if night-time data can be obtained. Although the 11 am and 11 pm acquisition times are not optimum, thermal inertia maps can be created which will provide information complementary to that obtained from the reflective region. The question still remains whether the orbit parameters are such that a day-night pass spaced 12 hours apart can be obtained. This is a mandatory requirement for obtaining reliable thermal inertia data.

Thermal inertia is generally correlated with density, but moisture content is also an important factor. Under reasonably dry conditions, distinctions such as limestone and granite vs. dolomite or quartzite, shale and marl vs. limestone and granite, and basalt and amphibolite vs. ultramafic rocks, should be achievable because of mineralogically related density differences. Also, some surface materials are distinguishable because of their different moisture retention properties.

Studies employing the thermal inertia approach have not been specifically directed towards altered rocks, but consideration of mineralogical and porosity changes during alteration indicates that some altered rocks might be distinctive. In general, thermal inertia might be expected to increase with increasing alteration intensity, due to decreasing porosity and increasing quartz content.

C. MAPPING OF GEOMORPHIC FEATURES

The following discussion does not include geomorphic features related to bedrock structures; these are treated in a later section on the mapping of structural features.

The nearly three-fold increase in resolution (from 80 m to 30 m) in the Thematic Mapper will significantly improve the capability to map glacial, fluvial, desert, and permafrost features, which are marginally observable or below the limits of detection on earlier Landsat imagery. A few examples are as follows:

1) Glacial -- individual drumlins within drumlin fields, Isette lakes, eskers, small kames, irregular boundaries of till plains and moraines.

2) Fluvial -- accurate drainage boundaries to correct existing maps, flood plain levees, abandoned meanders, braided stream channels, stream terraces, alluvial fans, scouring river bed channels.

3) Desert -- dune fields and sand seas, including the likelihood of improved classification of dune types, salt pans, and saline deposits not detectable at present Landsat resolution.

4) Permafrost -- Pengoes, and features which characterize polygonal or "patterned" ground.

Two improvements in addition to the increased spatial resolution will greatly increase the applicability of Landsat follow-on to coastal geomorphology and mapping: 1) the water-penetrating capability of the new blue spectral band (.45-.52 μm), and 2) the speed-up of data delivery to data centers by transmission from Landsat, via domestic communications satellites, directly to data centers such as EROS. Such mapping will increase our knowledge of dynamic coastal processes in both a fundamental way and in the solving of practical problems of coasts and harbour engineering. Such applications include mapping

seasonal changes along beaches, mapping erosional and depositional changes along coasts, measuring rates of constructional and destructional processes, mapping the changing geometry of land, both above and below water level, mapping subaqueous bedrock structures, shifting shoals, monitoring the effects of coastal engineering, providing guidance for dredging operations, monitoring (and ultimately predicting?) coastal landslides based on the mapping of soil moisture and the arcuate development at heads of slides. Related applications are mapping wetlands, monitoring illegal dumping in wetlands, mapping coastal subsidence in response to fluid extraction as in southern California, etc.

Much of the above applies also to the mapping of changes in the land-water interface of inland lakes and rivers. Shorelines of major lakes, for example, especially the Great Lakes, are subjected from time to time to severe modification and damage by major storms.

The water-penetrating capability of the .45-.52 μm band will also permit the mapping of suspended materials and the calculating of settling rates after storms. Reservoir filling patterns and rates of reservoir filling might become mappable and hence measurable.

An inescapable shortcoming of this wave band is that atmospheric haze will be about 3 times the signal strength, but digital enhancement of the data will hopefully diminish this disadvantage to a significant degree.

D. STRUCTURAL MAPPING

Structural mapping includes the delineation and analysis of all visible folds (anticlines, synclines, monoclines, structural terraces, etc.) and fractures (faults of all types, joints, etc.) revealed on the imagery. Most of the structural information derived from Landsat to date has been in the form of "linears", as well as curvilinear and arcuate features. These phenomena have been strikingly discernible on the Landsat imagery to date, due to the shadowing effect of the low sun angle (9:30 am time of equatorial crossing). The change of time to 11:00 am will result in a higher sun angle, fewer shadows and hence, diminished visibility of linears.

On the other hand, the three-fold increase in spatial resolution from 86 m to 30 m will provide at least two additional new contributions to the mapping of linear features: (1) The detectability of shorter

linears, which, in the extensive plateau areas of the globe can be expected to provide maps of <u>joint</u> systems; the increase in detectable linears may increase as much as two times, judging from a recent study which compared Landsat and Skylab imagery (86 μm and 10-30 μm resolutions, respectively); (2) a look at the "fine structure" of large scale lineaments which may be already mapped, but which have very complex surface expressions involving numerous smaller structures. This applies particularly to the lineaments of continental dimensions, many of which are known to be deep crustal avenues of recurrent movement and mineralization.

Unfortunately, effective and comprehensive structural mapping is not possible to achieve in the "monocular" mode of the present Landsat imagery. Stereo vision is needed to determine the inclination of dipping strata, the presence of fold structures and the direction and magnitude of offset (if any) along the faults (or linears). No doubt many of the "linears" mapped to date represent important structural phenomena, such as faults and folds, of varying magnitudes. Yet, their significance is clouded because they are perceived in only two dimensions, while in fact they represent profound three-dimensional elements to the geologic puzzle. Their correct interpretation holds the key to unlocking the chronology of geologic events responsible for the development of the structural framework and for the implacement of petroleum and mineral deposits in the subject area.

E. LINEAR AND LONG LINEAMENT MAPPING

Earlier Landsats have demonstrated the value of MSS imagery for the detection and delineation of tens of thousands of kilometers of hitherto unknown linear, curvilinear, and circular features. Many of these are now being investigated on the ground, by both conventional and geophysical methods. The goals of these ground investigations range from basic mapping and research into fracture pattern geometry and brittle deformation, to the search for indicators of petroleum and mineral deposits.

The linears detected by previous Landsats have utilized the oblique illumination provided by 9:30 a.m. equatorial crossing, the seasonal changes in sun angle and azimuth, and the seasonal changes in vegetation and snow cover. By the time the Landsat follow-on is launched, the EROS

data bank will include such multi-season coverage, gathered for eight years, at 18 days, and later 9 day cycles, by Landsats 1, 2, and C. Landsat C is scheduled for launch in the fall of 1977, and is expected to provide data into 1980. This means that each Landsat scene area will have been flown over about 120 times. This vast accumulation of repetitive data will provide an invaluable reference library for decades to come.

For the geological community, therefore, new kinds of data products will be welcome, however short of ideal they may be. Any change in time of equatorial crossing, for example, would provide landform shadowing from new angles, azimuths of solar illumination, and hence show up linear and curvilinear features which are not visible on existing Landsat imagery. The nearly threefold increase in resolution (from 80 μm to 30 μm) will provide at least two additional new contributions to the mapping of linear features:

1) the detectability of shorter linears, which, in the extensive plateau areas of the globe can be expected to provide maps of joint systems; the increase in detectable linears may be greater or lesser than two fold, depending upon the effects of trade-off between greater resolution and radiometry, and less oblique illumination. As will be amplified upon later, the ideal solution from a geological viewpoint would be the addition of stereoscopic capability which would far more than compensate for the lessened oblique illumination.

2) a look at the "fine structure" of large-scale lineaments which are already mapped, but which have very complex surface expressions and origins. This applies particularly to the lineaments of continental dimensions, many of which are known to be deep-crustal surfaces of recurrent movement and mineralization.

The preparation of regional fracture-lineament maps is vital to the growing need to ascertain which fractures are related to current earthquake activity. The proliferation of regional seismic networks (e.g. California, Missouri, the Northeastern States) is already providing a data bank of fault plane solutions. Companion brittle structure maps are now needed. Applications to nuclear power plant siting are obvious and compelling, in view of the National goal of energy independence by the late 1980's. The increased spectral resolution and radiometry may

be expected to contribute to the recognition of Holocene displacements along fractures, vital to the question of potentially active ("capable") faults as compared to those no longer active.

Concentrations of mineral resources are not randomly distributed around the earth but occur in unevenly distributed zones or regions. Mineral deposits in particular show systematic zonations parallel to lithologic belts, systematic changes across lithologic belts, correlations of minerals with age, rather than type of lithology, and localization of deposits or of disruptions and terminations of mineral zones along alinements transverse to lithologic belts. With exhaustion of easily locatable deposits, prediction of location of concealed bodies is imperative. Attempts to predict new mineral-rich areas have been made by relating the distribution of known mineralization to three tectonic concepts: 1) classical geosynclinal theory, 2) plate tectonics, and 3) crustal block tectonics. All three relate mineralization to linear elements in some way; the first to orogenic belts, the second to sutures, and the third to a pervasive system of crustal zones of weakness. The latter has been most extensively developed by Slavic scientists. English speaking scientists have concentrated on the first two, although a number point to their deficiencies and to examples in the U.S. of alinements of deposits that best fit the third. Some also point to local geologic, geophysical and topographic evidence that crustal fractures are reflected in both subsurface and surface materials.

The synoptic view of Landsat has permitted the recognition of a pervasive system or systems of long lineaments, many of which correlate with the crustal zones already postulated, and many of which represent new alinements. Research on these lineaments, and their relation to tectonic linear features, to crustal block boundaries, and to mineralized areas, has presented persuasive evidence that Landsat long lineaments do reflect crustal features that have controlled mineralization. Consequently, Landsat lineament study provides a new tool for the prediction of areas of concentration of the mineral resources we so desperately need.

As the study of lineaments involves the recognition of all long ones present, the building of a pattern reflecting the system or systems, and the analysis of their meaning in relation to regional tectonic, geophysical or mineralization patterns, once world-wide, multi-season

coverage is obtained, only views that are different in character or aspect are required. Landsat follow-on will provide this in terms of a higher sun-angle, and increased radiometric discrimination to enhance spectral differences that delimit many lineaments. Again, once worldwide, multi-season coverage is obtained, repeated views are not necessary. The value of repeated views to take advantage of surface changes (denudation, fault offset, etc.) will be felt in structural mapping and short linear study, directed to location of areas meriting detailed study, sampling, geophysics and drilling.

Increase in resolution will probably have little effect on the regional study of long lineaments, as their surface effects are generally diffuse in terms of 30 m. However, detailed study for exploration purposes will be assisted.

F. CIRCULAR FEATURES

Recognition of unsuspected circular features is perhaps the most unique immediate return from Landsat. The value of this phenomenon is readily apparent. Some represent buried volcanic centers, alined along earth fractures characterized by progressively offset eruption, and help in the prediction of progression of volcanic activity. Most outline calderas, ring dike systems, impact craters, or subjacent plutonic bodies, features known to have mineral deposits along their periphery, or contained within them, or which provide indicators of high temperature activity nearer the surface than elsewhere, and hence possible source areas of geothermal power. Others suggest basins, or domal structures in the sediments of those basins, guides to oil and gas, or saline deposits. The qualifications with respect to the value of Landsat follow-on described for long lineaments apply to circular features as well. The addition of capability for first approximation thermal inertia maps will be of additional assistance for exploration for geothermal power, although the data will probably be insufficiently detailed for more than corroboration of the potential of areas.

G. ARCTIC SEA ICE MAPPING

In the last ten years significant new resources of oil and gas, and of minerals, have been discovered in the North American Arctic.

In 1972, estimates of new reserves of oil ranged from 50 to 200 billion barrels, and of gas, from 200 to 1000 trillion cubic feet. In addition, the Canadian government estimated mineral reserves at 221 million tons in the Arctic Islands.

With exhaustion of reserves and social pressures to contain development activities in the populated temperate latitudes, the need to develop these Arctic resources and explore for more is accelerating.

The distribution and movement of sea ice seriously impacts winter exploration and transportation activities north of the Gulf of St. Lawrence on the east and the Aleutian Islands on the west, and summer activities roughly north of latitude 65°N. Land and sea areas of potential extend as far north as 85°N (Ellesmere Island, Greenland and Chukchi, Beaufort, Barents and Laptev Seas).

Sea Ice monitoring and forecasting impact transportation of exploration and development materials to the site and products from the site, providing knowledge of present conditions for navigation and predicting future conditions for route selection. This involves location and extent of navigable leads, bergs, floes, pressure ridges, and areas of weak and new or strong and old ice. Marine seismic exploration is similarly affected. Increasing use of on-ice winter seismic methods requires similar knowledge of leads, melt areas, pressure ridges, ice islands and surface roughness. Installation of off-shore platforms and loading facilities is impacted, as well as construction of between-island pipelines and overland pipelines at land-water interfaces.

Ice watch and forecasting, begun by surface methods, and later aerial surveillance, has been significantly advanced by the meteorology satellites. Minimum resolution on these, however, is about 1 km (NOAA 3-4). Landsat resolution of 80 m, and MSS discrimination of near-IR, has provided additional benefit.

The Canadian government, in 1973, assessed the benefits of a remote sensing system including sustained Landsat data (based on Landsat 1). They estimate an aggregate of $11 - $12 million in benefits by 1990 for all phases of Arctic exploration (Canada only), assuming an aircraft - NOAA - Landsat continuing system. Benefits directly allocable to Landsat are not completely identified, but some are as follows:

1. If Landsat data increased on-ice exploration by 1/2 mile per day, benefits would be $730,000 annually.

2. In 1973 Landsat imagery use yielded 75 miles additional shipborne exploration -- direct benefit of $100,000 (plus estimate of $400,000 additional surveying that would have been possible if data had been available in near real time.

3. Landsat identification of changing ice conditions could reduce shipping times at $50,000/ship day.

The greater resolution, increased spectral bands, and increased repetition of viewing will enhance the capability to identify and locate accurately floes, bergs, leads, new and old ice, pressure ridges, and melt water areas on ice, improving both exploration and development activities in the Arctic. The decreased sun angle from noon flight will be of little benefit or detriment, as the sun angle is universally low in the Arctic; however, the increase in atmospheric attenuation and disturbance generally experienced in the middle of the day may be deleterious. As positioning is of great importance in the ice, the increase in viewing angle producing geometric distortion of any significant amount is detrimental. On-ice relief is minimal, but position is obtained locally, commonly, with respect to high relief land areas. Accordingly, for effective use, geometric distortions should be routinely and rapidly removed before imagery is supplied to the user.

Of great interest is the change in orbit inclination that will result from lowering the flight altitude. Landsat now provides data only south of latitude 81°N; Landsat follow-on will provide data south of latitude 82°N. As potential resource areas extend north to about 85°, exploration will be enhanced by greater polar area coverage. However, the dynamic mechanisms governing the movement of Arctic ice extend to the Pole, and embrace the whole Arctic Ocean. The history of Polar ice movement and its current monitoring are basic to the International Ice Watch. Landsat took a significant cost/beneficial step forward in providing data for ice prediction and monitoring, Landsat follow-on will make a significant advance in this data by its polar coverage.

H. THE CASE FOR STEREO

The value of Landsat 1 and 2 for petroleum and mineral exploration has exceeded the expectations of many users and has made significant first-step contributions toward that end. Yet, Landsats 1 and 2 have not yet had the striking impact needed to meet the growing world-wide demand for energy and minerals resources. Although Landsat C and follow-on, as designed, will have important improvements to their forerunners, they will not square up to the needs of the exploration geologists, particularly the oil explorationist. In the view of many geologists, the greatest need is the capability for stereo viewing. The following discussion outlines the main arguments in defense of that statement.

Regional geologic mapping includes at least two basic facets, i.e. (a) lithologic mapping (discrimination of rock-type composition) and (b) structural mapping (folds, faults, etc.). This basic geologic map then becomes the data base interpretation and determination of the chronology of geologic events, from which effective petroleum (and mineral) exploration begins.

There has been very little basic geologic mapping of this type accomplished from Landsats 1 and 2, principally because of its lack of stereo capability. This is unfortunate, because photogeologic mapping of structural features and discrimination of rock types has been "state of the art" for many years, and should soon become part of the space package.

Instead of the basic geologic mapping, the typical Landsat reports for mineral and petroleum exploration are "specialty" maps, such as "Linears maps", anomaly maps of one sort or another, whose value is limited because the "first-step" basic geologic map is not available to provide the foundation for interpretation and guidance for sound exploration procedures.

Discrimination of Rock Type is the first phase of the basic geologic mapping process. The experienced photogeologist is able to routinely discriminate between the basic rock types to a remarkable degree of accuracy when the imager is viewed in the stereoscopic perspective. His efficiency increases rapidly with small amounts of ground truth. This is because the lithologic character of the bedrock produces unique land form and textures that can be readily recognized using stereo vision. The "form" and "texture" of the terrain, and the associated drainage patterns provide remarkable clues to underlying

lithology.

Therefore, to gain the greatest effectiveness of rock type discrimination using spectral data, it will be necessary to integrate these techniques with those of conventional photo interpretation of stereoscopic images. When this approach is utilized, spectral discrimination will be intensely pursued where conventional stereo techniques are ineffective.

Structural Mapping, includes the delineation and interpretation (evaluation) of all visible folds (anticlines, synclines, monoclines, structural terraces, etc.) and fractures (faults of all types, joints, etc.) revealed on the imagery. It is important to perceive and delineate the small and large structural features alike, since the smaller features are products of movements of the larger elements.

Effective and comprehensive structural mapping simply cannot be achieved in a "monocular" mode. Stereo vision is needed to determine the inclination of dipping strata and the direction and magnitude of offset (if any) along the faults (or linears). Most of the structural information derived from Landsat to date has been in the form of "linears" (as well as curvilinear and arcuate features) discerned on the imagery. No doubt many of these mapped features represent important structural phenomena, such as faults and folds, of varying magnitudes. Yet, their significance is clouded because they are perceived in only two dimensions while in fact they represent profound three-dimensional elements to the geologic puzzle. Their correct interpretation holds the key to unlocking the chronology of geologic events responsible for the implacement of petroleum and mineral deposits in the subject area.

When studied in stereo vision, most "linears" can be correctly interpreted as to whether they represent faults, and what type, and the direction and relative magnitude of offset, etc. This is particularly significant if the Landsat imagery is going to be an effective tool for answering many of the questions about the new global tectonics and the relationship of the world-wide regmatic sheer pattern to petroleum and mineral deposits. In addition to the foregoing, stereo mapping will greatly reduce the number of linear "false alarms" produced by faulty scan lines or cultural phenomena. Moreover, stereo viewing will reduce the need for low sun angle imagery, which is of major importance for monocular perception of structural features. The higher sun angle for

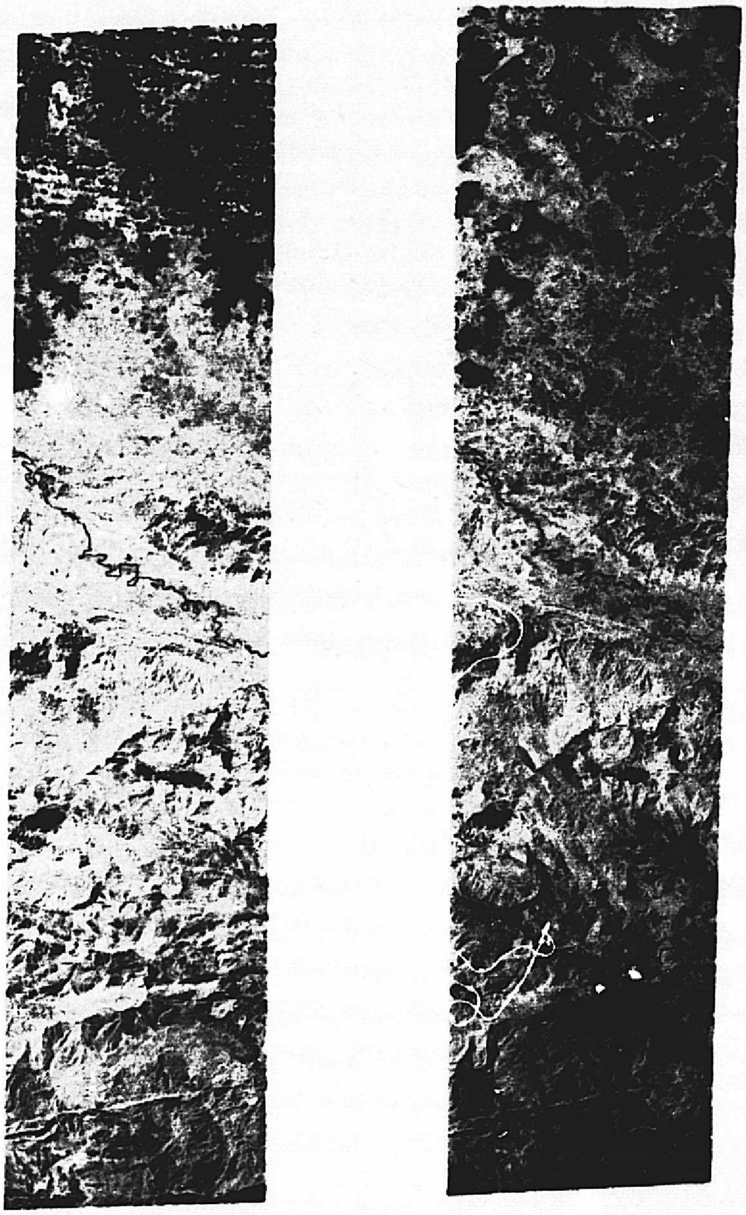
Landsat follow-on will reduce the amount of structural information visible as characterized on the earlier Landsat missions as a result of the shadowing effect. However, this will be offset if stereo viewing is available on this or other satellites.

The value of stereo mapping can be better shown than argued. Fortunately, some Landsat stereo is available, along the sidelap portion of the adjacent orbit tracks. The stereo effect is better near the equator where the satellite separation is greater, although here the amount of sidelap coverage is diminished.

The following examples are taken from a regional study of Guatemala, Southeast Mexico and Belize where Landsat imagery was used to produce a photogeologic map of an area of about 380,000 square kilometers to determine the geologic relations between the giant Mexican Reforma Oil Fields and the recent oil discovery in Guatemala by Shenandoah Oil Corporation, Fort Worth.

Figures V-1 and V-2 show stereo pairs which aptly demonstrate the value of stereo for geologic mapping and petroleum exploration.

2317-15522 1572-15554



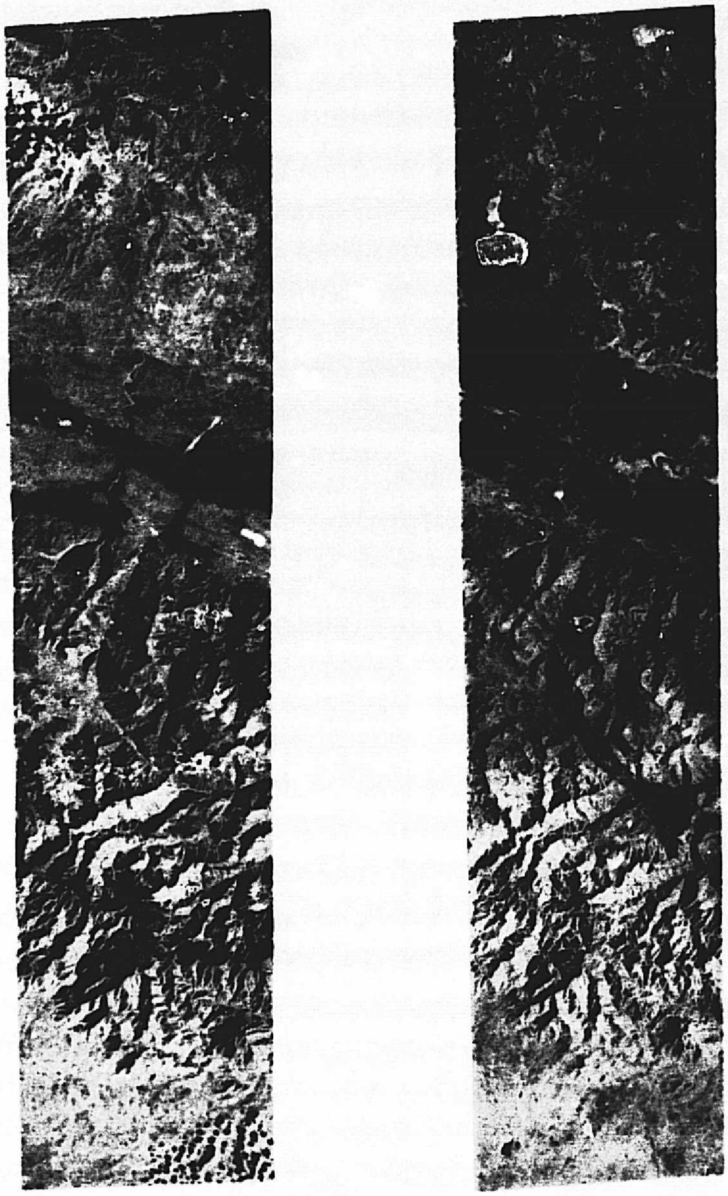
LANDSAT STEREO PAIR

PETEN BASIN
MEXICO-GUATEMALA

TGA Denver

Figure V-1

2317-15524 1572-15561



LANDSAT STEREO PAIR

PETEN BASIN
MEXICO-GUATEMALA

TGA Denver

Figure V-2

TABLE V-1
SATELLITE EVALUATIONS FOR MAPPING AND INTERPRETATION

Good (Neutral) Detrimental
3 2 1 0 -1 -2 -3

	Orthophoto Mapping	Mapping Rock Types	Geomorphic Mapping	Structural Mapping	Linears, Lineaments, Circular Features	Arctic Sea Ice	Average				
LANDSAT 1 and 2											
80 m Spatial Resolution	1	1	1	1	1	1	1.0				
Signal/Noise - Moderate	0	1	1	1	1	0	0.7				
Spectral Range 0.5 - 1.1 μm	2	1	1	1	1	1	1.0				
Repeat Coverage	1	1	1	1	1	3	1.3				
182 x 182 km mi. Format	3	3	3	3	3	3	3.0				
Mid-morning 9:30 a.m.	3	1	3	3	3	2	2.5				
Digital Tapes - Raw data	-1	2	2	2	2	0	1.2				
* Data Delivery as presently experienced	0	-2	-2	-2	-2	-3	-1.8				
* Image Quality as presently available	-2	-2	-2	-2	-2	-3	-2.2				
Incidental Stereo	0	-3	-3	-3	-3	0	-2.0				
Geometry - Excellent	2	1	1	1	1	1	1.2				
LANDSAT C											
Add: 10.4 to 12.5 μm	0	1	1	1	1	1	0.8				
* Digital Tapes, Corrected	2	2	2	2	2	0	1.7				
* Data Delivery, Rapid (48 hr.)	1	2	2	2	2	3	2.0				
RBV Panchromatic	2	0	1	1	2	1	1.2				
LANDSAT FOLLOW-ON											
30 m Resolution (except thermal)	2	2	2	2	2	2	2.0				
Add: Blue Band (water penetration)	2	1	3	0	0	0	1.0				
Add: Near IR (1.6 μm - mineral)	0	3	1	1	1	2	1.3				
Program Continuity	3	0	0	0	0	3	1.0				
Near-Noon - 11:00 a.m.	-2	2	-2	-2	1	2	-0.2				
Signal/Noise - Improved	1	3	2	1	1	1	1.5				
Geometry - Degraded at lower altitude	-1	0	0	0	0	-1	-0.3				
10.4 - 12.5 μm Day-Night coverage	0	2	1	1	1	1	1.0				
Resolution - better than 30 m	3	3	3	3	3	3	3.0				
Additional Spectral Bands											
Passive Microwave	0	1	0	0	0	2	0.5				
Radar	0	1	3	3	3	3	2.2				
Laser Topog. Profile	0	0	1	1	1	0	0.5				
Fraunhoffer Line Discrim.	0	1	0	0	0	0	0.2				
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	0	3	3	3	3	2	2.3				
8.2 - 9.4 μm (with 10 - 12 μm)	0	3	0	0	0	3	1.0				
Different Variable Time of Day											
Very low sun angle	1	-3	2	2	2	-2	0.3				
Night (for thermal IR)	0	2	1	1	1	1	1.0				
Non-Sun synchronous	0	0	3	3	3	0	1.5				
Day + Night IR (Max T)	0	3	1	1	1	3	1.5				
Stereo Coverage - complete w/vert. exag.	3	3	3	3	3	0	2.5				
* Additional Pre-processing of digital data											

* = Ground Station Function

TABLE V-2
APPLICATION ASSESSMENT TABLE

Application:

Description of Mapping and Interpretation Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Orthophoto Mapping		
Morphologic, hydrologic and cultural features in contrast, clearly discernible.	Characteristic shapes or tones, linear patterns (ridges, streams, shores, property lines).	Capability for discrimination same as Landsat; increased resolution makes more detailed maps possible; greater spectral range may improve map image quality.	Experience on Landsat shows digital processing for rectification and enhancement still necessary.
Earth features in true position with respect to each other.		Capability to recognize control points better than Landsat; capability to position deficient as increased sensor angle causes radial distortion, particularly in high relief areas.	Narrow angle sensor view is required. Excessive digital correction required.
	Mapping Rock Types		
True reflectance in spectrum bands to which mineralogy responds; signal strong enough to read clearly through vegetation, atmosphere; thermal inertia data.	Spectral reflectance values for minerals characteristic of unweathered lithologies or altered products, i.e., limonite, hematite, hydrous/anhydrous, silicic/mafic, calcareous, saline.	1.55-1.75 band maximizes rock reflectance, minimizes vegetation, separates more lithologies; noon flight maximizes signal but also atmospheric effects; 10-12 μm band provides step toward thermal inertia maps.	Lack of 2.2 band fails to differentiate anhydrous unaltered limonitic from altered is less optimal for non-iron lithologies.
	Geomorphic Mapping		
Drainage, ridge, coastal forms, glacial features.	Shapes: hogbacks, cuestas, mesas, ridges, arretes, trenches, oxbows, braided streams, meanders, levees; bars, beaches, reefs, cusps, banks; drumlins, eskers, kames, moraines; mature, youthful, old drainage, dendritic, trellis; pengoes, polygonal ground, beaded streams.	Increased resolution improves capability, but high sun degrades capability by lack of shadow; greater spectral data probably a help.	Shadow or stereo required.
	Structural Mapping		
Folds, faults, lithologic differences.	Short linears (straight, arcuate, disrupted) tonal differences, drainage texture, shadows.	Resolution will enhance detail amount, spectral data enhance lithologic differences and continuity, lack of shadow detracts from ability to determine what morphology detail shows and what structure.	Stereo needed if no shadows, otherwise lower sun angle.
	Linears, Lineaments, Circular Features		
Alined morphologic features, or tonal contrast boundaries.	Ridges, valleys, rifts, trenches, all shown by shadow reflecting relief; vegetation, soil, or soil moisture change, shown by spectral reflectance.	Same as Landsat, with improvement because of "new" view and increased spectral data, diminished by lack of shadow.	One-time complete world-wide multi-season coverage with Landsat plus Landsat follow-on aspects probably sufficient.

TABLE V-2 (Cont'd)

APPLICATION ASSESSMENT TABLE

Application:

Description of Mapping and Interpretation Problems

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Arctic Sea Ice Mapping		
Real-time identification of floes, bergs and direction movement, leads, new ice, many-year ice, pressure ridges, water on ice.	High water/ice contrast, spectral contrast new and old ice, surface roughness, repetitive and real time.	Resolution an improvement in detail as is spectral addition.	Real-time data to user a must, and coverage of as much of the Arctic as technologically possible is imperative.

APPENDIX A

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APPENDIX B

ACRONYMS

ASG	Applications Survey Group
C	Centigrade
CCT	Computer Compatible Tape
DCP	Data Collection Platform
EROS	Earth Resources Observation Satellite
HFU	Heat Flow Unit
IR	Infrared
JPL	Jet Propulsion Laboratory
L-1	Landsat 1
L-2	Landsat 2
L-C	Landsat C
L-Fo	Landsat follow-on
MSS	Multi-Spectral Scanner
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
RBV	Return Beam Vidicon
r. s.	remote sensing
SLAR	Side Looking Airborne Radar
TM	Thematic Mapper
USGS	U. S. Geological Survey

APPENDIX C

RESUMES

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Ph.D.	Rice University

He has worked in the Petroleum Industry in Production Geophysics and Research Geophysics for several major oil companies. He has taught mathematics at several major universities. Upon completing his Ph.D. at Rice University in 1973, he became a research mathematician in charge of setting up a digital capability for processing satellite data at Exxon Production Research Company.

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B.A.	Mount Holyoke College
M.S.	Stanford University

Senior physicist concerned with research and development of improved remote sensing methods for detecting geothermal, geochemical, and geophysical features associated with energy resources. Developed design concepts, instrumentation and technology for measuring thermal radiation from hot plasmas; supervised field measurements; directed laboratory research in soft x-ray spectroscopy; developed Power-Law Thermal Model that provides rationale for measuring precise terrestrial temperature differences less than 1°C; studied natural surface temperature and emissivity variations and their spectral features from aircraft and spacecraft infrared data. Areas of professional interest and other information: atomic and solid state processes; x-ray and geochemical terrestrial anomalies associated with energy resources; their unique spatial, spectral, temporal and thermal radiation features distinguishable by aircraft or spacecraft methods.

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Donovan's principal research interests are in the geology of petroleum, especially the physiochemical controls on hydrocarbon migration, the chemistry of hydrocarbon-pore water-rock systems, and the direct detection and remote sensing of near-surface manifestations of subsurface hydrocarbons.

From 1963 to 1968, he was an exploration geologist with the Mobil Oil Corporation engaged in field and subsurface basin analysis studies throughout the major basins of Alaska. In 1968 he began teaching at Midwestern University while also researching the general problem of petroleum migration and microseepage. He joined the U.S. Geological Survey in 1972.

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Consultant Advisor to Corps field offices on engineering geology aspects of design and construction of Civil Works projects. Technical Monitor for Corps Civil Works R & D in geology, geophysics and rock mechanics. OCE point of contact for geology applications of remote sensing.

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B.A.	Simpson College
M.S.	Iowa State University

He is currently the manager of the Earth Resources Information Department, Geoscience Division, Petty-Ray Geophysical. As a service organization, the Earth Resources Information Department provides the exploration industry with Landsat digitally processed imagery and geologic interpretation generally in a regional context. Previously, he has worked as a seismologist with Petty-Ray's Seismic Interpretation department with interpretations experience in such areas as the U.S. East Coast, Gulf of Mexico, Offshore California and the Gulf of Alaska.

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A.B.	University of California, Berkeley
M.A.	University of California, Berkeley
M.P.A.	Golden Gate University

Began work as a geologist with the California Division of Mines and Geology in 1950, with various progressions of duties and advancement to Chief Deputy in 1974, and present "acting" job in 1975. Most technical experience in mine examinations, State Geologic Map field mapping, and commodity specialist for sand and gravel, stone, specialty sands, iron and steel. Coauthor of Los Angeles County and San Bernardino County reports, several commodity projects, and Alturas and Westwood sheets of State Geologic map. His most recent study was Urban Geology Master Plan for California (co-author) in 1972-73. Almost entirely administrative now.

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B.S.	California Institute of Technology
M.S.	California Institute of Technology
Ph.D.	California Institute of Technology

Came to JPL in 1970 to continue lunar studies and apply remote sensing techniques, particularly image processing, developed for planetary work, to earthly problems. Principal Investigator in both ERTS and Skylab programs developing methods for remote geologic mapping and detection of mineralized zones using orbital photography. Presently manager of the Planetology and Oceanography section at JPL.

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A.B.	University of Rochester
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Ph.D.	University of Texas at Austin

He has been with the Bureau of Economic Geology since 1968. Research has been oriented toward mineral resources and the environmental aspects of their extraction and use. Associate Director for Administration of the Bureau 1971-75. Also Associate Professor, Department of Geological Sciences.

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B.S.	Stanford University
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1974-Present	Lawrence Berkeley Laboratory - Geoscientist
1972-1974	Hend Company - self owned economic geology consulting firm.
1971-1972	Frost & Associates - Consulting economic geologist
1969-1971	Kaiser Aluminum - Senior Resident Geologist, Argentina
1965-1969	St. Joe Minerals Company - Mine; Research Geologist

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B.A.	Syracuse University
M.A.	Washington University
Ph.D.	Cornell University

District Geologist (and for 5 months Acting Chief, Geological Branch) on Colorado Plateau for AEC, 1953-1957, with temporary exploration assignments in Colombia and Turkey. In 1957-1958, Professor at State University of New York at Plattsburg, since then research geologist with N.Y.S. geology survey, also Adjunct Professor at Rensselaer Polytechnic Institute and SUNY-Albany. ERTS-1 investigator to extract maximum geological information over N.Y.S.; currently studying brittle deformation and contemporary vertical movements in New York.

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B.S.	University of Missouri at Rolla
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I have spent the last 26 years of my career in various aspects of geological research for the Exxon Corporation through its production research laboratory. My fields of specialization have been petrography, mineralogy, economic geology, and the application of remote sensing to minerals exploration.

LATHRAM, Mr. Ernest H.
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B.A.	Miami University, Ohio
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1946-1976 (Retired 1/76)	Geologist, U.S. Geological Survey. Geology of Alaska including: mapping in sedimentary, metamorphic and igneous terrains for petroleum and mineral assessment, sandstone petrography, photogeology, compilation of small scale regional maps, regional tectonic analyses, marine seismic studies, and investigations of Landsat applications to geology, tectonics and metallogeny. Assistant Chief, Alaska Branch (1952-56), Assistant Chief, Office of Marine Geology (1966-70), EROS Representative, Pacific Coast/Alaska (1972-76).
1942-1946	Intelligence (photo, radar), U.S. Armed Forces.

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B.S. (Hnr.)	University of West Australia
Ph.D.	University of California, Berkeley

West Australian mining geologist, who has worked in research and teaching in Australia, Utah, California and briefly in Europe, Canada and Brazil. Mainly concerned with instrumental analysis of rocks and γ-ray to Landsat, SLAR to thermal infrared. Recently he has worked principally towards geobotany and biogeochemical aspects of satellite digital data.

MARRS, Dr. Ronald W.
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Gp.E.	Colorado School of Mines
Ph.D.	Colorado School of Mines

Dr. Marrs has professional experience in both geology and geophysics. While employed by Chevron Oil Company (1966-1969) he worked in offshore exploration and in geophysical research; including work in gravity and magnetic prospecting and in seismic methods. While pursuing his graduate studies at the Colorado School of Mines, Dr. Marrs spent three summers doing geologic mapping and geophysical field work. He also began his training in remote sensing, as a graduate research assistant. He presently has seven years experience in remote sensing work. For the past four years (1972-present) he has taught remote sensing methods and directed the remote sensing research program at the University of Wyoming. Dr. Marrs has been involved, as an investigator, in both the Landsat and Skylab projects. He has also conducted several other research projects attempting to apply remote sensing as a tool to resource problems.

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Ph.D.	University of Colorado

Eighteen years experience in engineering and environmental geology and remote sensing as consultant, and government contractor. Principal investigator on six government contracts, most recently, P.I. on Skylab EREP. Lectures in geology at U.C.L.A. since 1970.

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Ph.D.	Yale University

Mapping and economic geology, New York State Survey (1957-59), USGS in Pakistan (1961-65) and Brazil (1965-66); U.S.G.S. lunar geologic studies, mapping of terrestrial impact structures (1966-69); U.S.G.S. remote sensing research and applications (1969-); currently coordinator of uranium geophysics program and working on problems of uranium remote sensing and mapping of structure from images.

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Duties include supervision and coordination of geologic mapping, mineral resource investigations, groundwater studies, geologic hazards evaluation, remote sensing applications, coastal studies, topographic mapping and geodetic control.

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B.S.	University of Nevada
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Physical Scientist (Staff Scientist), U.S.G.S.-EDC - 1973-present.

Professor of Geology (Economic Geology - Remote Sensing), Colorado School of Mines - 1969-1973.

Geologist, U.S.G.S. - 1950-1969.
Staff Geologist, Professor, Staffing and Res., Contracts and Grants (Dep. Assoc. Chief Geol.);
Chief, N. Nev. Geophysical Project;
Iron Commodity Geologist;
Visiting Professor, Econ. Geol., U. Rio Grande do Sul, Brazil (on loan to AID);
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B.C.E.	City College of New York
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Ph.D.	Purdue University

Dr. Rib's major responsibility is to ensure that aerial survey techniques, including photogrammetry, interpretation, and illustrations, are utilized to their greatest effectiveness by Federal and State highway engineers. Toward this goal he is involved in developmental and cooperative projects, instructional courses and consultation services. Prior to assuming his present position, he was responsible for FHWA's major research efforts in the use of remote sensing systems and computer analysis techniques for evaluating soils and terrain conditions for highway applications. He is also a visiting Professor at the University of Maryland teaching courses in remote sensing and site investigations.

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Joined the Branch of Astrogeology of the U.S. Geological Survey in Flagstaff, Arizona, in 1964. Principal research was in lunar geologic mapping using small-scale satellite images, and he also worked on the Geological Survey's Lunar Orbiter Program, coordinating phases of geologic analysis of the possible Apollo landing sites. In 1969, he joined a small group of geologists and geophysicists to form the Remote Sensing Geophysics Section, which now constitutes the Geological Survey's main research effort in this field. As Staff Geologist for Remote Sensing from 1972 to 1974, Dr. Rowan coordinated the geologic remote-sensing program during the Landsat 1 and Skylab experiments. His current research focuses mainly on spectral and spatial analysis of Landsat, Skylab, and aerial photographs and images, especially as applied to mineral exploration.

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Employed at Chevron Oil Field Research Company since 1955; current position of Senior Research Associate. Academic background of geologic field mapping, stratigraphy, and structural geology. Professional activities in petroleum exploration, subsurface mapping, sedimentary petrography, stratigraphic traps. Research and application of all types of remote sensing technology beginning in 1965. Adjunct Professor of Geology at University of Southern California, 1966 to present. Regent's Professor of Geology at U.C.L.A., 1975; Adjunct Professor currently.

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B.S.C.E.	Purdue University
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Worked at Purdue University from 1949 to 1955 on development of engineering applications of airphoto interpretation, particularly for soils and rock identification, highway studies, permafrost and trafficability analyses. Since 1955 have been with the U.S. Army Corps of Engineers working on engineering studies and investigations, many of them concerned with the interpretation of aerial photographic, radar, and infrared imagery. Prepared environmental studies based on field work, airphoto interpretation, and references. Project director on the fabrication of a change detector, to detect changes or differences between two sets of remote sensor imagery taken at different times.

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Geologist for U.S.G.S. from 1963-present. Worked on Apollo Program from 1964-1974; principal investigator for Geology Experiment for Apollos 14-15; presently Staff Geologist for Telegeology, Geologic Division.

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4 years petroleum exploration - Standard Oil of California.

1964-present - U.S. Geological Survey, Astrogeology, geology of the moon, member of Mariner 10 TV Team studying geology of Mercury.

1974-present - User of Landsat imagery.

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Mr. Trollinger has had more than 20 years experience in geological exploration in the majority of sedimentary basins in North and South America and Alaska, and in many regions of Europe, Africa, and Asia. His primary contribution to photogeological mapping has been in the area of practical application of geomorphic principles towards petroleum and mineral exploration. In recent years TGA has led the way in the use of space photography and imagery for natural resources surveys around the globe.

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B.A. Math	Louisiana Technical University
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Ph.D. Geology	University of Michigan

Dr. Vincent has had ten years experience in geological remote sensing, starting with four years (1966-1970) in the Lunar-Planetary Research Branch of Air Force Cambridge Research Labs (Bedford, Mass.) as a Captain in the U.S. Air Force. In 1970 he joined the Environmental Research Institute of Michigan (Ann Arbor, Mich.), which he left in 1974 as a Research Geophysicist. In 1974 he founded Geospectra Corporation, where he now serves as company president. Dr. Vincent's Ph.D. thesis was on the use of infrared remote sensing for rock-type discrimination. He has been a principal investigator on both Landsat and Skylab projects and has published over 45 papers and technical reports on geological remote sensing.

PART 3

INLAND WATER RESOURCES

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CHAPTER I

INTRODUCTION AND OVERVIEW

A. INTRODUCTION

The purpose of this report is to present an evaluation of the Landsat follow-on system relative to its impact on the problems of Inland Water Resources. The evaluation was developed in terms of accomplishments that can be achieved with conventional data and the current Landsat program.

Chapter II provides a comprehensive treatment of the problems encountered in fourteen areas of water resources. The problems of these areas are discussed in detail, especially with respect to data requirements. The pros and cons of conventional versus Landsat 1 and 2 data sources are examined and then used as a base for assessing the impact of the proposed Landsat follow-on program.

B. THE ROLE OF LANDSAT REMOTE SENSING IN WATER RESOURCES MANAGEMENT

1. Brief Problem Outline

The evaluation of Landsat data applications to water resources management encompasses nearly all of the task assignment subjects on inland water resources to some degree. Water resources management begins with the watershed or drainage basin and ends with application of water by the user. The water manager must concern himself with numerous water parameters such as quality, quantity, seasonal distribution, and water loss. In moving water from the watershed to the user, he must continually evaluate collection, storage, transportation and distribution systems, control facilities, and the efficiency of the total system.

The problems of surface water management vary considerably from one part of the United States to another and from season to season. In most western states water is a critical resource that must be managed within limits set by state law and interstate compacts. Surface water may be used and re-used numerous times until it is lost through evapotranspiration back into the atmosphere or becomes unusable because of salt concentration. Use of available groundwater may be limited to withdrawal at a fixed rate based on a formula which may include saturated thickness of the aquifer and a predetermined number of years of production set by some agency. When the groundwater reservoir is

depleted, land values drop and use must be changed because in most western states groundwater aquifers received little or no recharge, and once depleted, recovery may take hundreds and possibly thousands of years.

In the northwestern, eastern and southern states, the problems with water are nearly opposite in nature. These states generally have an excess of water--groundwater aquifers are full to overflowing and streams and rivers flow most of the year. Streams, rivers and lakes are used for many purposes, to dispose of municipal and industrial waste, as water supplies, for transportation, and power generation. A major concern of the water manager here is to control and regulate stream flow, reservoir levels, water quality and thermal pollution.

Remote sensing from satellites, such as Landsat, and aircraft is directly applicable to surface water resource management. One characteristic of water that aids in differentiating surface water from land areas is the ability of water to adsorb radiation in the infrared region. This characteristic increases the contrast on certain types of images sensitive to the infrared spectrum (.7 - 1.5μm). Bands 6 and 7 of Landsat 1 and 2 cover the near infrared region (.7 - 1.1μm) and provide images with good land water contrast that are well suited to surface water resources management. The current MSS (multispectral scanner) carried by Landsat 1 and 2 has four bands (4, 5, 6, and 7) covering a spectral range of 0.5 - 1.1μm and having a resolution of 80 meters or approximately 1.2 acres. In the area of water resources management this resolution capability has proven to be marginal in many applications.

NASA's proposed Landsat follow-on thematic mapper system has six bands covering the following spectral ranges: band 1 (0.45 - 0.52μm), band 2 (0.52 - 0.60μm), band 3 (0.63 - 0.69μm), band 4 (0.76 - 0.90μm), band 5 (1.55 - 1.75μm), and band 6 (10.40 - 12.50μm). The thematic mapper is capable of 30 meters resolution in bands 1-5, and 120 meters in band 6. The expanded frequency coverage, improved resolution and accuracy should overcome many of the marginal features of Landsat 1 and 2. In water management, object identification either through spectral analysis or image analysis is essential to provide accurate evaluation of hydrologic parameters.

Landsat has shown that satellite data can be applied to water resources management for both surface and groundwater. The satellite with its remote data collection platform relay capability has been proven to be versatile. Applications of Landsat data to water resource management range from watershed analysis to snow mapping and from surface water inventory to near real-time flood damage assessment. Salomonson (1976) has tabulated some of the demonstrated key Landsat capabilities for water resources management (Table I-1).

A more detailed outline of Landsat applications to water resources management is suggested in Table I-2.

Landsat data is currently being utilized in both digital tape and image forms. To obtain maximum information from Landsat data, computer processing of digital tapes is necessary; however, manual interpretation is less costly in many cases and requires a minimum of equipment.

One serious shortcoming of Landsat is its MSS resolution; approximately 80 meters. Scientists have been driven to seek means of extending the data beyond its limits through very complex techniques requiring highly specialized equipment or programs. No reasonable dollar cost can be placed on this pursuit, but the point of diminishing returns appears to have been reached. The next step is obvious and NASA appears to be in the process of justifying taking that step--increase the capability and resolution of future earth resources satellites based on cost-effectiveness and state-of-the-art technology.

The cost effectiveness of using Landsat data for water resources management over conventional approaches cannot be fully assessed at this time because there are no truly operational projects utilizing Landsat data. A number of quasi-operational tests have been conducted using USDA/SCS models, USACE models, EPA 208 program studies, and snow survey programs, but the cost effective ratios are probably biased by the fact that these are tests using highly qualified personnel to do most of the actual work.

A review of available literature gives a good indication of the application of Landsat data to water resources management. Most studies reviewed were sponsored to some extent by NASA and conducted by State and Federal Government agencies, universities, or consultants.

Table I-1. Demonstrated Key Landsat Capabilities for Water Resources Management

A. Watershed Land Use/Surface Cover and Flood Plain Studies

- Hydrologically relevant land uses and surface cover information (impervious fraction, vegetation density, etc.) including fractional watershed coverage can be obtained and displayed at scales up to 1:24,000.
- Landsat data have been acquired on a seasonal basis and compiled for engineering design and planning studies using watershed models in 1/4 to 1/30th the time required using conventional approaches.
- Cost figures range between 1-4/km^2 and cost savings could be 15-20% for the average urban watershed study.
- Quasi-operational tests have been accomplished using USDA/SCS models, USACE models, and in EPA 208 Program studies.

B. Snow/Ice Surveys

- Snowcover variations have been monitored on watersheds as small as 6 km^2 and snowline altitudes estimated with accuracies up to ±60 meters.
- Significant correlations of early snowmelt,snowcover,and seasonal runoff have been obtained and studies completed showing that satellite snowcover data should improve the performance of snowcover runoff prediction models.
- A quasi-operational test of satellite snowcover observations is occurring in the Western States involving 6 Federal and State agencies.
- Observations of glaciers can very effectively be acquired for mass balance, glacier movement, and inventory studies.

C. Surface Water Surveys Including Flood Surveys and Wetlands Monitoring

- Costs of surveys are 1/10th that for using conventional techniques.
- Lakes larger than 1 hectare can be detected and changes in lakes larger than 4 hectares monitored.
- Major vegetation species on Coastal Wetlands can be delineated at scales up to 1:125,000.
- Lake area estimation accuracy can be ±8% at 5 hectares and ±1% at 500 hectares.
- Landsat imagery assessed as a fast,accurate,and relatively inexpensive method of compiling flood data for disaster planning and post-flood analysis.
- Quasi-operational applications of these data have been accomplished through surface water surveys in Oklahoma and Tennessee by U.S. Army Corps of Engineers, Texas Water Right Comm., and the SCS in Oklahoma.

D. Water Quality Surveys

- Suspended solids concentration in near surface layers can be estimated to ±5-10% over the range from 0-900 ppm.
- Landsat data can be used in better choosing the location of in-situ measurements, identifying anomalous water quality regions, and extending monitoring to areas not normally accessible by land or boat.
- The trophic status of lakes can be surveyed quickly (re: Minnesota).

Table I-2

Outline of Landsat Data Applications for Water Resources Management.

(A) Surface Water

(1) Watershed Management

a. Evaluation of watershed parameters.

b. Prediction of annual runoff volume and peak flow periods.

c. Estimation of maximum and minimum runoff volumes for gaged and ungaged watersheds.

(2) Reservoir Management

a. Water quality and quantity measurements.

b. Real-time data collection system.

(3) Stream Hydrology

a. Evaluation of stream parameters.

b. River mechanics.

c. Flood control.

d. Flood plain studies.

(1) Flood plain characteristics and mapping.

(2) Flood hazard.

(3) Flood damage assessment.

(4) Water Quality

a. Suspended load.

b. Eutrophication of surface water bodies.

c. Water quality measured by DCP's.

(5) Soil Moisture

(6) Surface Water Inventories

(7) Snow and Ice Surveys

(8) Hydrologic Land Use Classification

(B) Ground Water

(1) Delineation of Recharge and Discharge Areas

(2) Delineation of Aquifer Boundary Conditions and Areal Extent Based on Geologic Structure

(3) Location of High Yield Water Wells

(A) Surface Water

(1) Watershed Management

The application of Landsat data to evaluation of watershed characteristics has been attempted by many agencies of State and Federal governments along with universities and independent research groups. Their primary objectives have been to predict maximum and minimum runoff values, annual runoff volume, and peak flow periods. These are the watershed characteristics which most concern the water resource manager. By being able to evaluate these values, reservoirs, flood control structures, and water distribution systems can be adequately designed; reservoir operations can be made more efficient; maximum beneficial use of surface water can be realized; flood hazard reduced, and surface water can be more efficiently administered.

Watershed analysis and the accuracy of runoff predictions have made significant gains in recent years through watershed modeling and use of advanced computer techniques. Many of these models are formulated so that the watershed processes operating between the precipitation input and river runoff output depend upon coefficients that are related to land use and surface cover characteristics, stream order, stream length, drainage density, basin area, basin shape, slope, stream gradient, etc. Variables that must be considered in watershed modeling include precipitation (type, amount, and distribution), other weather conditions and solid moisture. Research efforts have shown that Landsat can provide much of the required information through MSS images or digital tapes, and DCP's in a more timely, representative, and cost effective manner than can be achieved using conventional approaches.

Landsat has been demonstrated capable of providing land use and surface cover data for basins as small as 20 km^2 (Salomonson, 1975). Physiographic parameters such as stream order, stream length, basin area, basin shape, and drainage density, etc. have been assessed using Landsat data by a number of investigators. Range (1975) found that, in general, for watersheds studied in Wisconsin, Colorado, and the Middle Atlantic States certain parameters such as basin area, shape, and stream sinuosity could be obtained from Landsat data with a detail equal to or exceeding that on 1:250,000 topographic maps depending upon relief and vegetation cover.

(2) Reservoir Management

Reservoir management, whether for water supply, flood control or both generally relies on real-time data systems. The New England Division, Corps of Engineers, undertook a study to determine the usefulness of data products received from satellites including Landsat. Some of the Landsat applications include phenomena such as:

(1) Location and coverage of surface water, especially flood and low flow periods.

(2) Icing conditions on rivers, lakes, and reservoirs.

(3) Turbidity, sedimentation in lakes and reservoirs.

(4) Location and extent of snowcover.

(5) Location and extent of excessive precipitation accumulation.

(6) Tidal levels and flooding at or near hurricane barriers.

(7) Soil moisture conditions.

The studies also include Data Collections Platforms (DCP's).

The Corps has employed 26 remote reporting stations (DCP's) as part of a data collecting system operating throughout New England. The system relays hydro-meteorological information such as river stage, precipitation, wind and water quality parameters to Reservoir Control Centers in near real-time. The primary purpose for the overall system is flood control and serves as an operating model for future designs.

The New England Divisions system has been proven feasible and reliable. The Corps has stated that orbiting satellite systems can be designed that are more feasible, easily maintained, and less expensive than conventional ground-based data collection systems.

(3) Stream Hydrology

Large scale stream hydrologic parameters can be evaluated from Landsat data such as stream sinuosity, order, length, density, gradient, sediment load and change. Range (1975) has reported that watershed parameters, incuding stream sinuosity were obtained from Landsat with a detail exceeding that of a 1:250,000 scale topographic map. Satellite data at present is more valuable for its synoptic coverage for large streams and rivers. McGinnis and Range (1975) have applied Landsat data to flood monitoring on the Mississippi River. Van Es, Gomez, and Sveter (1975) successfully used Landsat data in a similar manner to determine areas of inundation on the Lower Magdalena-Canca River Basin, Columbia.

Flood hazard, flood damage estimates, flood plain characteristics, and flood control are potential applications for Landsat data. The New England Division, Corps of Engineers has successfully applied Landsat data combined with DCP data to many of the mentioned areas of stream hydrology for reservoir management and operation (Buck, Horowitz, and Foran, 1975). Baker, Holz and Patton (1975) have demonstrated the utility of orbital and suborbital remote sensing in flood hazard studies. Although their study used Skylab acquired data in conjunction with aircraft acquired data, the sensors and applications are valid for Landsat and suggest the potential for sensors to be carried on Landsat follow-on vehicles.

(4) Water Quality

Landsat data has been used to successfully evaluate certain water quality parameters. Using computer processing of Landsat-1 multispectral digital data, Johnson, et al, (1975) were able to evaluate nuisance levels of chlorophyll and sediment loading of the Choptank River, Maryland. Results correlated closely with automated analysis. They suggest that for the purpose of water quality analysis, under favorable atmospheric conditions, only MSS bands 4, 5, and 6 are necessary.

Water quality analysis using Landsat data is limited to those parameters that have a visible signature of some type or can be correlated to some physical change that does. Dissolved solids and chemical parameters cannot be measured directly from Landsat data; however, they can be measured by remote Data Collection Platforms (DCP's) and relayed through Landsat for correlation with Landsat data.

(5) Soil Moisture

Soil moisture is one of the most important hydrologic parameters in water resources management because it is indicative of groundwater conditions and essential for determination of watershed runoff characteristics, solid infiltration rates, soil moisture deficiency, etc. Soil moisture when combined with other hydrologic parameters can be used to evaluate recharge and discharge area of drainage basins, crop conditions, and groundwater boundary limits and conditions.

Soil moisture levels can be used in estimating flood hazard associated with precipitation events. Landsat has been shown to be capable of detecting soil moisture differences and areal distribution

of precipitation events; however, Landsat lacks a real-time data distribution capability for image data. As a result, estimating flood hazard for real-time applications using Landsat data is not practical at this time, but represents a potential for future systems. The data Landsat is capable of providing is valuable in estimating flood hazard through analysis of watershed characteristics and flood plain mapping.

The present Landsat system also lacks a means of quantifying soil moisture condition, so that only relative measurements are possible. Experiments on Skylab using a microwave sensor, passive and active, have shown a good potential for measuring soil moisture (Eagleman and Lin, 1975). A microwave sensor capable of measuring soil moisture would have the advantages of increasing the accuracy and reliability of evaluating soil moisture conditions on watersheds to aid in runoff predictions, in agricultural areas to determine crop conditions and efficiency of irrigation practices, in evaluating groundwater aquifer parameters, etc. In addition, such a system may have the potential of determining the water content of snow in watershed areas.

(6) Surface Water Inventory

Landsat data has been used successfully to inventory surface water bodies as small as 0.01 km^2 (Range, 1975). The U. S. Army Corps of Engineers has been employing Landsat data for locating and counting bodies of water larger than 0.02 km^2, calculating their area, identifying their shape, and locating dam sites on major rivers in response to Federal legal requirements. The Texas Water Board in 1975 proposed to use Landsat data to inventory Playa lakes in the high plains of Texas. The study is intended to produce an operation program and will use the Detection and Mapping (DAM) package developed by NASA.

Inventory of surface water bodies larger than 0.01 km^2 appears to be operational or near operational. However, many private lakes and ponds are less than 0.01 km^2 in area. In most parts of the country construction of ponds and reservoirs is tightly regulated. Landsat data could be used to identify new construction and to regulate these small ponds with increased resolution. The proposed thematic mapper system should provide a great advantage in evaluating most water resources management parameters.

(7) Snow and Ice Surveys

One very significant feature of Landsat's ability to record precipitation events is that snow areal extent can be readily mapped. In mountainous areas snow pack may account for 50 to 60 percent of annual runoff as in the Upper Rio Grande drainage basin of Colorado. Snow mapping by Landsat may prove to be the key for making near real time runoff predictions which are essential for efficient management of water resources. If an increase accuracy of 10 percent for runoff predictions can be realized, this could mean as much as 158,000 acre-feet of additional water could be used for irrigation in Colorado. This water could be used for increased production or to satisfy interstate compact commitments.

Snow mapping has been carried out successfully in Wyoming and India. As a result of these studies, NASA has sponsored operational application of satellite snowcover observations in four western states including Arizona, California, Colorado and the Northwest. In these operational projects identifying snow under tree cover and distinguishing snow from clouds has been a major problem area. These problems may be overcome by interpretation technique, computer enhancement of data, increased resolution of the thematic mapper, or sequenced images coupled with ground truth.

Accurate prediction of snowmelt runoff depends on delineating the snow line from bare ground, rock, clouds, and under tree cover. Landsat 1 and 2 have serious shortcomings in this respect. The 80 m resolution is insufficient for fixing the snow line to a geographical position less than ±60 m under optimum conditions (Meler, 1975). Studies done by Meler (1975) have also shown that snowcover can only be mapped effectively in watersheds as small as 6 km^2 in area. These limitations can seriously affect an operational program particularly where real time or near real-time runoff predictions are necessary.

Attempts have been made to measure water content of snow using Landsat data. Sharp and Thomas (1975) have described a dual sampling technique using Landsat data and conventional methods. Their results indicate an advantage over using conventional methods alone. A microwave sensor may provide water content of snow directly. Such a system is highly desirable for developing a means of snow mapping and runoff

predictions in ungaged watersheds. Empirical methods for forecasting runoff based on snowcover and other hydrologic data for a basin are a reality today, but such methods are applicable to gaged basin only.

Ice conditions can be surveyed from Landsat data for lakes and pack ice. Ice conditions on lakes and rivers affect surface evaporation rates and stream hydrology. Ice jams on rivers can produce flooding as well as barriers to water transportation. Ice on reservoirs significantly affect surface evaporation. For large and inaccessible reservoirs, Landsat images could be used to economically determine the extent of ice cover for computing evaporation losses. No studies of this type have been attempted that the author is aware of.

(8) Hydrologic Land Use Classification

Classification of land use is necessary in watersheds and drainage basins because land use affects runoff characteristics, infiltration, and evapotranspiration losses. All of these elements are used in hydrologic modeling as part of the mass balance equation for the system. In order to achieve the greatest accuracy in modeling a watershed or drainage basin, land use must be classified and the areal intent of each class known.

Landsat data combined with extensive ground truth can be used to produce land use maps at scales as large as 1:24,000. Generation of maps at this scale is dependent upon computer enhancement and manipulation of digital data, a very costly process. Smaller scale maps are less expensive and serve most hydrologic applications just as well.

One example of applying Landsat data for hydrologic land use classification and mapping was performed by Ragan (1975). He has used Landsat data to obtain land use and to estimate degrees of imperviousness on the Anacostia Basin in Maryland. Subsequently, peak flow predictions were produced using Landsat data and the results compared with similar results obtained from large scale aerial photos (1:4300). Land use classification in terms of percent of watershed cover agreed quite well with land use estimates obtained from the large scale aerial photographs. Four man-days were used to process Landsat data compared to 94 man-days for processing large scale aerial photos. Physical features of drainage basins can be extracted from Landsat imagery to reduce the standard error in equations used to estimate streamflow characteristics. Hollyday (1975) has reported reducing standard error by 10 percent.

There are numerous studies on land use classification based on Landsat data, and almost as many techniques as studies. An analysis of the literature on this subject is beyond the scope of this report.

(B) Groundwater

Management of groundwater resources presents an almost entirely different set of problems for management of surface water resources. The basic water parameters of quality, quantity, and seasonal distribution are similar for both; however, evaluation of groundwater parameters is another matter. To effectively manage groundwater resources, aquifer characteristics must be established such as areal extent, saturated thickness, boundary conditions, coefficients for storage and transmissivity, and recharge and discharge areas. Many of these characteristics cannot be evaluated through use of remote sensing techniques, such as saturated thickness and coefficients of storage and transmissivity which must be tested in-situ. Other aquifer characteristics may be evaluated indirectly from remote sensed data, including recharge and discharge areas, through analysis of land use, vegetation, stream patterns and types, land forms, and geologic structure. Some aquifer characteristics may be evaluated directly if conditions are favorable. For example, in many western states where vegetation is sparse, and geologic formation and structure are evident, aquifer boundary conditions and areal extent may be mapped directly.

The application of Landsat data to groundwater resources management has been limited. One significant application has been in locating high yield wells in areas of crystalline rock or areas underlain by dense relatively impermeable sedimentary rocks. Bands 6 and 7 can also be used to delineate soil moisture conditions within a given area so that areas of recharge and discharge can be evaluated. Where geologic structure is apparent, aquifer boundary conditions can be estimated; and by combining all of the visible hydrologic parameters the gross groundwater aquifer system may be evaluated.

2. Conclusion

Landsat 1 and 2 data in conjunction with remote Data Collection Platforms (DCP's) have proven the value of satellite data collection and application to water resources management. However, the resolution of

the MSS and limited spectral coverage are marginal for most operational applications. The cost is very high for interpretation or analysis using advanced techniques to derive the maximum information from Landsat data. For long term repetitive applications or for small area coverage the cost is prohibitive.

One means of reducing interpretation cost of the user is to increase image resolution, thereby reducing the need for highly sophisticated interpretation equipment. Increased resolution would also improve the accuracy and reliability of data taken from images or digital tapes and at the same time add greater versatility to data applications. The increased resolution of the Landsat follow-on thematic mapper is a step in the right direction with its 30 meter resolution capability. Ultimately, resolution of 10 meters or less may be needed for special applications requiring identification or recognition of objects such as vegetation types or various structures. With the advent of Space Shuttle and a potential means of servicing satellites, very high resolution photographic film and cameras could possibly be used to provide 10 meterresolution or better on a regular basis and at an economical level.

One major shortcoming with Landsat is that none of the present on-board sensors can be used to provide quantitative measurements of hydrologic parameters such as soil moisture. A high resolution thermal scanner such as the one proposed for the thematic mapper will provide a valuable tool that may result in quantitative techniques, when combined with other sensors. Thermal data from aircraft have been correlated with soil moisture. A thermal scanner-equipped satellite may help solve some of the problems of differentiating one parameter from another such as snow from clouds or bare ground.

Microwave,either passive or active,may also provide a means of developing quantitative techniques,particularly in measuring hydrologic parameters. Skylab has demonstrated the potential of such a system. Such a system is highly recommended for development and application on future satellites.

Real-time image acquisition cannot be obtained from the present system; however, the nine day coverage of Landsat 1 and 2 is adequate for most purposes. Ultimately a stationary satellite with high resolu-

tion sensors and a pointing system may be needed as applications and techniques in water resources management become more sophisticated. Immediate consideration should be given to increasing resolution and spectral coverage over Landsat 1 and 2 in order to develop quantitative techniques and lower cost operational applications.

In essence, the sensors and specifications proposed for Landsat follow-on appear to be near optimum for most water resource management applications. The thermal infrared sensor could provide a means of developing quantitative techniques for evaluating hydrologic parameters. The proposed system is a logical step towards a truly cost effective, operationally oriented system.

C-3

CHAPTER II

APPLICATION OF CONVENTIONAL AND LANDSAT DATA IN SPECIFIC PROBLEM AREAS

This chapter presents the state of the art development of the applications, followed by the background, traditional approaches, current Landsat role, and impacts of Landsat follow-on for each of these applications.

Two different tables are utilized to help assess Inland Water Resources applications with respect to Landsat, and are shown when appropriate in each discussion on application involvement. The Application Assessment Table outlines different aspects of the application with regard to the information needs, parameters invovled, and Landsat follow-on feasibility. The Requirement Assessment Table shows the relative requirement level of different data characteristics which could be available on Landsat type satellites. The contents of the tables have been contributed to by a wide cross-section of users and are therefore somewhat repetitive and even divergent in nature. As with the text, most of the content is "un-edited" to preserve the individual contributor's view points.

A. SNOWCOVER AND RUNOFF FORECASTING

1. Background

In many areas, especially the western United States, runoff from the snowpack represents a major portion of the annual yield. Early prediction of the snow pack runoff is an important element in the overall management of the water resource. These predictions allow managers to develop recommendations concerning acreages that should be planted and plans developed for reservoir operations. If snow pack estimates indicate a year of low runoff, acreages should be cut back, while an early estimate of a high runoff year would allow more land to be brought into production. These predictions are extremely important. The earlier the estimates can be made, with confidence, the more efficient the planning and management processes.

2. Traditional Approaches

Traditionally measurements of snow water content, depth, and density were made to monitor the accumulation of snow, define the maximum snow-pack (which generally occurs in the Western States between mid-March

to mid-April), and relate the snowpack to a forecast of snowmelt runoff. Data generally did not become available until February and ended in May. Uses of water have become so competitive and critical, though, that water managers are increasingly demanding frequent information about the snowpack to make early season decisions (October, November, December) about irrigation, flood control or power releases. Even more demanding is information during melt-off (April, May, June), as the pack recesses. It's a big advantage to the water manager to know what is "left to come". It is during recession of the snowpack that satellite snow mapping has its greatest potential benefit.

3. Role of the Current Landsat Program

Landsat 1 and 2 provide the means for the USER, through his own efforts, to obtain the extent of snowcover, a mean snow elevation, and snowcover within selected elevation bands. Interpretation of satellite imagery to obtain snowcover is generally done by hand methods using a grid system, planimetering areas, etc. Help is obtained by some aids such as the Zoom Transfer Scope, density slicing, color additive techniques, and multispectral classifiers such as the "Image 100".

The forecaster needs clues to the melt rate of the snowpack. Ways to determine this through satellite imagery are not yet available, but an effort is currently being made through the ASVT program. If the ASVT effort shows snowcover does add a valuable parameter to water supply forecasting techniques, then snowcover data from satellites will be necessary to perform the water supply forecasting task, and the USERS will be ready to use the data.

Preliminary investigation in the ASVT's indicated that snowcovered area has potential for use in an independent procedure for updating or correcting water supply forecasts as the snowmelt season progresses, as well as in some aspects of modeling snowmelt runoff. Snowcovered area from satellite imagery, however, constitutes only one source of input data for water supply forecasts and updating. Utilization of snowcovered area will not completely eliminate the need for data from other sources. As a consequence, it can not be said that snowcovered area from satellite imagery will materially reduce the cost of a snow survey or water supply forecasting program. In fact, it is recognized

that there will be some additional cost for acquisition, reduction, and application of this additional data from satellite imagery in current forecast activities, but the potential value of an independent forecast procedure in making water management decisions does have tangible as well as intangible value to water managers. When data from satellite programs are available on a timely basis with sufficient frequency of observation, they could provide an important supplemental source of information, but "cost effectiveness" of snowcovered area from satellite imagery is not definable in the ASVT forecast programs at this time.

Progress on adapting snowcover to runoff forecasting so far has been in "research", and the need for research continues. Only until we can establish whether there is real operational need and value to snowcover in forecast procedures can we then try to establish a "cost effectiveness". It's really not practical to attempt a cost effectiveness study while still in the research phase. The largest costs to the operational USER now is studying the value of snowcover and in developing or modifying formulas and models to accommodate snowcover. Eventually the cost of data reduction using snowcover (or other satellite derived data) into the forecast models would become relatively minor.

It's difficult right now to put a dollar value on using snowcover in runoff forecasting for many reasons, including such intangibles as providing coverage in wilderness areas, or safety of aircraft. Still to be evaluated is the improved accuracy of satellite snowcover compared to fixed-wing aircraft and whether inclusion of snowcover will end up with a better forecast. However, the potential benefits in terms of more efficient use of water are of such magnitude that even a 1 or 2 percent improvement in the forecast schemes due to satellite data should well offset the costs involved in adding the satellite information to the forecast schemes.

An add-on benefit to the use of satellite imagery is in the area of being able to ascertain if farmers and ranchers are indeed cutting back during low water years and adding on during big years. Another is in monitoring windblown fields in erosion prone areas, which has been attempted but is experiencing some difficulty. Another is in evaluating the effect of gravel mining along major streams, and finally,

classification of cloud cover for estimation of areal precipitation over mountainous basins.

There are a number of problems associated with the present use of Landsat data. Receipt of the imagery now takes about four weeks, too late for operational purposes, but still valuable for build-up of an historical record which is required for runoff forecasting. Further, coverage during the snow accumulation period is generally sufficient with nine-day intervals, since accumulation occurs gradually, except that immediate monitoring of intervening storms may be lost. Nine-day intervals during the snow melt-off period is not adequate since melt-off occurs quite rapidly. The problem is exaggerated if heavy cloud cover is present on the day of the satellite pass.

Right now data interpretation is a concern to the operational USER. The forecaster usually has little time for a very time consuming analysis of the imagery. If interpretation is done by an operator, techniques need to be developed such that any interpreter will get essentially the same results. Using digital data will be an advantage if the cost can be kept reasonable, and if interpretive noise can be minimized so that consistent results will come from such problem areas as "exposed rocks vs. snow", "snow under forests vs. brush cover", and "snow vs. clouds".

4. Impact of Landsat Follow-on

a. Throughput. Rapid throughput of the satellite data to the USER is essential for operational snowcover mapping and snow runoff forecasting. The satellite data must be available to the forecasting agency within 48-72 hours after satellite passage. It's impossible right now to establish the value of having satellite data arrive quickly, but its value in forecasting becomes zero if delayed very long. It then only has value as a verifier. An example of the rapid changes which can occur in snowcover is shown in Table II-3 for four watersheds in Arizona during the 1974-75 season. A quick-look option in the throughput system would be a great advantage in forecasting runoff.

b. Coverage. Repetition between coverage is a vital factor. Nine-day coverage frequency may be adequate for routine snowcover observations in many areas of the western United States during the period of snow accumulation, but it is not adequate anywhere during the period of snow melt-off. If two or more cloudy days occur in a row at each nine-day

Date	Verde River Subwatershed 3		Verde River Subwatershed 3		West Clear Creek		Upper Tonto Creek	
	Area (km^2)	% Area	Area (km^2)	% Area	Area (km^2)	% Area	Area (km^2)	% Area
1974								
17 Dec.	153	5.2	43.5	1.5	36.6	5.9	0	0
1975								
4 Jan.	1022	35	953	33	556	90	290	16
1 Feb.	--	--	1092	38	613	99	126	6.9
9 Feb.	826	28	399	14	369	60	121	6.7
18 Feb.	1543	53	1463	51	617	100	1269	70
27 Feb.	904	31	509	18	476	77	99	5.4
17 Mar.	1378	47	1059	38	617	100	256	14
4 Apr.	506	17	425	15	390	63	49	2.7
22 Apr.	159	5.4	35	1.2	27	4.4	1.8	0.1
10 May	0	0	0	0	1.9	0.3	0	0

TABLE II-1

Results of Computer Analysis of Snowcover on Selected Subwatersheds in Central Arizona from Landsat Imagery

pass during melt-off then the satellite imagery has lost its value. Problems may be encountered during either accumulation or melt-off. During the snow season lost satellite coverage due to cloud cover could have an effect on such user decisions as flood forecasting, where an attempt is being made to evaluate the effect of rain on snow; early season irrigation (October, November, or December), where the decision to make releases or not is based on what snowpack is already available; or power releases where knowing the expected remaining runoff is valuable so as to avoid having to "spill" water. More frequent repetition between coverage would maximize the chances of getting relatively cloud-free imagery. Landsat imagery must be closely repetitive to watch the progress of snowmelt; and a repeat cycle shorter than 9 days would be desirable. It is not worth another satellite for snowcover alone, though.

c. Interpretation. Landsat imagery probably has more than adequate resolution for snow mapping, more accuracy in fact than an interpreter is capable. So long as the imagery is operator interpreted it remains interpretation dependent, and its accuracy is dependent upon the interpreter. But the high resolution of Landsat doesn't "hurt" the snow mapping effort.

Various techniques to aid in interpreting the imagery are available and have been tried. The least expensive is still the operator method of data reduction. The use of various machine aids such as a density-slicer, "Image 100", etc. helps reduce the variation in interpretation, but at this point in time these are generally slow, expensive, and not readily available.

Digital computer interpretation of Landsat imagery has been successfully demonstrated as technically feasible, and may eventually be the way to go. The costs of digital reduction, at the USER level though, are large compared to operator interpretation. It suggests that perhaps a centralized digital computer should make available to the USER the "results" derived from Landsat imagery (within the operational time needed), as opposed to sending the USER the imagery and technology needed to interpret the data. (In either case, of course, the USER would have to implement the data.)

d. Bands. Having various spectral bands is desirable and has proven to be of value in snow mapping. The addition of Band 5 (1.55-1.75

micrometer wavelength) on the proposed thematic mapper should be valuable in helping to distinguish between snow and clouds, or between snow and exposed white rock. (Some clues are presently available by comparing MSS Band 7 vs. MSS Band 4.) Thermal imagery, to be provided by Band 6 (10.4-12.5 micrometer wavelength), should provide a potential for determining portions of the snowpack that are melting.

e. Orbit. Changing the equatiorial crossing time to 11 a.m. will have varying effects on snowcover determination. The build-up of excessive cloud cover over mountain areas is apt to be greater in mid-day than in the morning during the snowmelt season when snowcover observations are of greatest value. The lesser shadow effect of a mid-day vs. early morning crossing is not a significant factor, but could improve the determination of snow under trees. The mid-day crossing will mean a more pronounced difference in rock temperature vs. snow temperature, which may provide more contrast in Bands 5 and 6 of the thematic mapper. Also, snowmelt will be more advanced at mid-day and perhaps easier to detect. The lower orbit and higher power of the Landsat follow-on would not have a significant effect on determining snowcover.

f. Auxiliary Data. Data from satellite imagery is giving us information in the form of snowcover which before has not been available to the snowmelt runoff forecaster. Besides snowcover, though, it would be desirable if auxiliary instrumentation aboard the satellite could record "something" (such as albedo, or attenuation of electromagnetic energy) which relates to water content of the snowpack. These, or any other system of relating water content, are only valuable, however, if they can give a more accurate measurement than the present methods of measuring water content (which we know works). Of course if there were no access to any data about water content, then a satellite based sensor at whatever accuracy would be a desirable thing. But since we do have a reliable way of obtaining water content it becomes more difficult to justify expenditures, but doesn't mean we shouldn't investigate and research such satellite-held devices.

B. HYDROLOGIC IMPACT OF CONIFEROUS FOREST COVER CHANGES

1. Background

Assessment of the hydrologic impacts resulting from forest cover changes involves most of the subject areas of the Inland Water Resources Applications Survey Group, as well as other groups, including: (1) Land Use, (2) Agriculture/Range/Forestry, (3) Environment, and (4) Geology. The objective of this report is to discuss where the various remotely-sensed parameters can best be used in determining hydrologic impacts of forest cover changes.

This discussion is based on the writer's conviction that satellite imagery can best be operationally utilized as inputs to dynamic simulation models of hydrologically complex watersheds. Accordingly, the parameters are presented in terms of a comprehensive model that: (1) is formulated in terms of the diverse form, structure, and arrangement of natural forest stands; and (2) at least qualitatively accounts for the hydrologic response of these stands to management, based on the best information available.

This model has been developed for an area of the United States in which the writer has some familiarity (the Rocky Mountain Subalpine Zone). It has been programmed to run on a digital computer, and is designed to predict the short- and long-term hydrologic response to forest cutting. While this discussion is site specific, many of the principles outlined herein which are pertinent to subalpine hydrology are also applicable elsewhere.

First of all, the hydrologic setting of the subalpine zone is described, followed by a discussion of those hydrologic processes affected by forest cover changes. Finally, the remote sensing parameters which are pertinent to the analysis of the various processes are summarized and referenced to the discussion in the body of the report.

This material has been summarized from several recently published Forest Service reports (McPherson, 1970; LARS Mil. Study; Bauer CSU; Huber, 1975; and ASCE Anac.).

The subalpine zone, as defined in this report, consists of high-elevation forested watersheds with old-growth stands of primary lodgepole pine, Engelmann spruce-subalpine fir, Douglas-fir, and aspen (respectively, Pinuw contorta, Picea engelmannii-Abies lasio-carpa, Pseudotsuga menziesii, and Populus tremuloides). Geographically, the

area considered lies in Montana, Wyoming, Colorado, and New Mexico.

Some significant hydrologic characteristics of subalpine watershed are:

Hydrologic Characteristics of Subalpine Forest

- Little, if any, overland flow of water appears at any season, and the quantity of eroded soil is generally small
- Mean annual temperature does not exceed Z$^{\circ}$C (35°F), and mean annual precipitation is approximately 50-75cm (20 to 30 inches).
- Total precipitation is about half snow and half rain. With the exception of south slopes, there is no snowmelt during winter until after early March.
- Of the total precipitation, about one-half is stored in winter snow accumulation and is released during the spring melting period.
- More than 95 percent of the total streamflow occurs from April through June.

Water-balance studies in central Colorado have given us insight into the hydrology of spruce-fir and lodgepole pine forests. Water yield is 45 to 55 percent of the annual precipitation. Of this amount, 90 to 95 percent is derived from snowmelt. Typically, winter conditions keep the snowpack well below freezing until late March or April. Peak seasonal snow accumulation averages 15 inches of water equivalent, and during the melt season, the depleting snowpack is augmented by more than 5 additional inches of precipitation. Subsequent rainfall during the summer and early fall averages 8 to 10 inches. Thus, of this 28- to 30-inch input, about 12 to 15 inches becomes streamflow.

The determination of hydrologic impact of coniferous forest cover changes is, in and of itself, a modeling exercise. Once this impact on the water balance of a basin can be determined, the output can be utilized in a systems analysis approach to the overall description of the hydrologic characteristics of the basin.

Water resources management is not simply the determination and description of the physical aspects of a particular watershed but, rather, is an integration of technical, social, economic and political constraints into a planned use of the resource which meets the majority of demands by the majority of the people. The determination of the impact of forest cover changes is an important part of the input needed to arrive at a management plan in that adverse forest cover changes can

result in earlier hydrograph peaks which deplete late season stream flows when demand is greatest; increased sediment loads, which can cause siltation of reservoirs and water quality problems; and many other changes in the physical response of the watershed which can have serious economic and social impacts.

The inputs required to accurately model subalpine watersheds are many. The most important can be summarized as follows:

Precipitation
Snow Redistribution
Radiation
Evapotranspiration
Timber Harvesting Patterns
Reflectivity
Soil Moisture

2. Traditional Approaches

a. Precipitation. Most snow survey and precipitation records are suspect, due to the effects of wind on snow accumulation and gage catch. Because snow accumulation and rainfall in subalpine forests are strongly influenced by wind, which interacts with the vegetation and local topography, the existing system of precipitation gages and snow courses in the Rocky Mountain region can at best give only index values of areal precipitation. Seasonal snow accumulation varies from a uniform snowpack having systematic variation with elevation in densely forested watersheds to extremely irregular patterns in large park-like areas surrounded by trees.

Ground-based snow survey methods can indicate how the seasonal snowpack is distributed on most subalpine watersheds. Once the snowpack begins to melt, however, snow surveys can no longer be used to estimate precipitation input. At this point, and during the summer and fall, rain gages are often used, which in most cases give questionable results due to a host of interrelated factors. Many of these factors have been researched for several hundred years. Because research using ground-based sensors has largely reaffirmed past results without producing new knowledge, new and different systems which measure precipitation above forest canopies must be developed.

APPLICATION ASSESSMENT TABLE

TABLE II-2

Application:

Forest Cover Change Modeling

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
Reflectivity	Variation in tone or brightness between forest canopy and nonforest areas.	Good	
Temperature	Indicated variations in brightness on a Thermal IR image.	Marginal	
Transmissivity	Density of canopy cover.	Good	
Soil Water	Variation in soil temperature, soil albedo, microwave brightness.	Marginal	
Snow Redistribution	Areal extent and bare spots. Also depth and water content.	Fair to Poor	

b. <u>Snow Redistribution</u>. Redistribution of snow is an important phenomenon in the subalpine zone. Snow rests on tree canopies only during periods of cloudy weather, low temperature, and frequent snowfall. Typically, after snowfall ceases, wind-generated vortexes and eddies quickly strip the snow from the trees. In a short time this airborne snow is redeposited at varying distances from where it was intercepted.

When forest cover is partially removed, the new aerodynamic change in roughness modifies the patterns of snow accumulation, so that more snow accumulates in the cutover area (provided that openings are small) and less accumulates in the uncut forest. For optimum snow accumulation, openings should be protected from wind and should not exceed eight times the height of the surrounding forest. Larger openings apparently allow wind eddies to scour the snowpack near the center.

Conspicuous increases in snow accumulation near the center of small forest openings is largely offset by decreases in snowpack below the trees so that total snow storage on watersheds subjected to cutting is not changed. However, when openings are large, watershed snow storage may be decreased through large sublimation losses and transport of snow out of the basin.

c. <u>Radiation</u>. Research in subalpine forests has shown that radiation is usually the major source of energy for snowmelt. Accordingly, shortwave and longwave radiation represent the primary energy components available for snowmelt.

In order to evaluate the radiation component the following parameters must be determined:

(1) Incoming solar radiation,

(2) Reflectivity of snowpack,

(3) Shortwave radiation transmissivity coefficient,

(4) Forest cover density,

(5) Air Temperature,

(6) Snow surface temperature,

(7) Site aspect.

d. <u>Evapotranspiration</u>. A "potential" evapotranspiration function has been developed for subalpine watersheds based on empirical temperature

dependent equations such as the Hamon equation which requires latitude, converted to saturation vapor density.

The evapotranspiration computed by this expression requires the following input:

(1) saturated water vapor density (absolute humidity) at the daily mean temperature,

(2) daily shortwave radiation,

(3) potential shortwave radiation for the day.

e. Timber Harvesting Patterns. Natural or man-made changes in the forest cover will produce changes in runoff by affecting the energy balance, patterns of snow accumulation, and consumptive use. For example, at Wagon Wheel Gap in the headwaters of the Rio Grande in Colorado, snowmelt rates were accelerated after clearcutting an aspen-mixed conifer forest from one 200-acre watershed. Annual water yields were increased about 22 percent during the 7-year period that records were taken after harvest cutting. Conventional methods of determining harvest patterns have been through the use of aerial photography.

f. Reflectivity. Studies of the energy balance and associated vapor loss indicate that the major variations with regard to latent heat flux are associated with reflectivity of the timber stand. The following parameters must be determined to arrive at the impact of reflectivity on latent heat:

R_f = the reflectivity of the forest stand,

R_{fo} = the reflectivity of a forest opening.

g. Soil Moisture. The critical point at which available soil water begins to limit evapotranspiration varies with time and forest tree species (not Meteorological conditions).

3. Role of Landsat and Landsat follow-on

Many of the hydrologic processes affected by forest cover changes in the subalpine zone can be studied using remote sensing from spacecraft. Such data would not only be useful in evaluating short-term hydrologic changes but also for monitoring long-term changes as forest cover is re-established on cutover areas. The remote sensing data required for making these assessments would come from several disciplines including: (1) snow hydrology, (2) timber management, (3) wildlife habitat, (4) geology, and (5) soil survey. Table II-3 summarizes remote-sensing data requirements.

Considerable research effort in remote sensing has been expended in studying the separate components of Table II-3 in the writer's opinion, the results of this work can best be put to practical use by utilizing satellite imagery as inputs to a dynamic systems analysis of the problem. As seen in Table II-3, a variety of satellite imagery could be utilized in hydrologic impact assessment. Some information on hydrologic processes such as snow accumulation and melt and soil/water/vegetation relations would be required on a short-term basis, whereas other data on forest cover characteristics, such as density, reflectance, transmittance, and emittance, would be obtained at less frequent intervals.

4. Conclusion

The proposed Landsat follow-on parameters are apparently designed to obtain the maximum information possible on forest vegetation and snow. Accordingly, they would find direct application in describing the hydrologic processes summarized in Table II-3. There is currently a need for information of the type which will be available from Landsat follow-on in resource management. The United States Forest Service is utilizing procedures similar to the one discussed in this report in assessing the multi-resource impacts of forest cover changes. There are large sums of money being spent on these activities. Moreover, these activities will continue to have an ever expanding role in day-to-day operations.

C. SOIL MOISTURE

1. Background

A knowledge of the soil moisture and its distribution is important to many people. For example, it is important to the agriculturalist or forester when evaluating plant response or production, to the hydrologist when compiling water balances, to the flood forecaster when estimating peak flows that may occur in a given drainage, and also to many others whose activities are related to the soil. Historically, soil moisture has been primarily determined on a point-by-point basis in an X, Y, and Z coordinate system. Since soil moisture is also a function of time, the discrete point measurements have value only over a limited time span. When working with discrete point samples, the

TABLE II-3

Remote Sensing Data Required for Assessment of Hydrologic Impacts of Forest Cover Changes in the Subalpine Zone

Parameter	Hydrologic Process
Reflectivity	Snow accumulation and melt Evapotranspiration
Temperature	Snow accumulation and melt Evapotranspiration
Transmissivity	Snow accumulation and melt Evapotranspiration
Forest cover density	Snow accumulation and melt, Evapotranspiration, and Snowpack Redistribution
Soil Water	Evapotranspiration
Snow Redistribution	Snow accumulation and melt, and Evapotranspiration

practical limitations of time and expense normally limit the number of samples taken. This is one of the major reasons which has led to the estimation of soil moisture by various schemes. There is, however, a need to produce regional or synoptic patterns of soil moisture on a repetitive schedule. Such information would assist in planting scheduling, estimation of crop yields (particularly in a dryland operation), estimation of irrigation requirements and irrigation scheduling, and hopefully in improved water-runoff forecasts. Regional or synoptic pattern definition of soil moisture appears to be a task well suited to remote-sensing technology.

Soil moisture is an important input to runoff modeling. It is also one that must be continually evaluated. The degree of improvement in water resource models that can be obtained with better soil moisture data would be a function of the specific area, and purpose of the specific model. In general, however, some improvement should be expected.

2. Traditional Methods

The most common methods of measuring soil moisture in the field can be placed in six categories, as follows:

(1) Gravimetric
(2) Electrical-resistence methods
(3) Heat-diffusion methods
(4) Absorption methods
(5) Tensiometric methods
(6) Penetration methods
(7) Radioactive methods (non-airborne)

These methods have been reviewed by Johnson (1962), and the reader is referred to this publication, which also contains an excellent bibliography. It is interesting to note, however, that Johnson states:

APPLICATION ASSESSMENT TABLE

TABLE II-4

Application:

Soil Moisture

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
Topographic Relief Vegetation or Lack of Vegetation (includes land use).	Stereo coverage tones and textures.	Better than Landsat 1 and 2.	
Soil Surface Temperature	Selected I-R wavelengths.	Thematic mapper.	Warm soils tend to be dry soils.
Microwave Brightness Temperature	Selected wavelengths.	Negative	Vegetation still appears to be a major problem although some progress is being made.
Soil Albedo	Spectral reflectance.		

> The gravimetric method is concluded to be the most satisfactory method for most problems requiring one-time moisture-content data. The radioactive method is normally best for obtaining repeated measurements of soil moisture in place. It is concluded that all methods have some limitations and that the ideal method for measurement under field conditions has yet to be perfected. (Johnson, 1962)

Thus it has been inferred that the use of point measurements to determine soil moisture on a areal basis was far too time consuming and expensive for most projects. To stress this point two studies are cited.

Reynolds (1970a) studied the variability of soil moisture in the uppermost 8.0 cm of the soil profile over a range of soil types. For plots 3.1 x 1.9 m he found that "A sample size of 10 individuals is usually sufficient to estimate the mean moisture content to ±10% at the 95% probability level." He goes on to point out that if the vegetation is grass the 10 sample points will normally provide an estimate within ±5%. If however the vegetation is "bracken", i.e., ferns, coarse bunch grass, etc., then 10 to 25 samples will be needed to achieve the ±10% figure. He notes that to go from ±5% to ±2% at the same confidence level generally requires considerably more samples.

Because of the limitations of point-sampling techniques, various techniques have been devised to estimate the soil moisture (Blaney and Criddle, 1950; Baier and Robertson, 1966, 1968; Thornthwaite and Mather, 1955a, 1955b, 1957). The knowledgeable reader will note these references only refer to a small but significant portion of the literature on estimation of soil moisture. The reader should also realize that limitations of point measurements also may, to some extent, apply to remotely sensed soil moisture. For example, some techniques, as will be discussed later, are applicable only to the top few cm of the soil mantle. Thus estimations of moisture at root depths deeper than this must still be made.

3. Role of Remote Sensing in Soil Moisture

The instrument package of the current Landsat program does not provide a good approach to the determination of soil moisture. Thus,

little has been done directly with the Landsat. However, extensive experimentation has been conducted with other satellites and aircraft sensors. The experiences with these systems can be used to evaluate the potential strengths and weaknesses of the Landsat follow-on program.

The 1974 Snowmass Summer Study report by the Inland Waters Group (Crook et al. 1975) considered the remote sensing of soil moisture. It was classified as having high relative benefits on both a local and regional scale. The spatial resolution desired was from 80 to 300 meters. The periodicity of coverage was a function of the specific task and hence ranged from daily to annually. The speed of data delivery deemed appropriate was also considered to be task specific but should range from 2 to 60 days. While these goals have not been met at the time of this writing, exciting progress has been made.

The general approaches which appear feasible have been reviewed by Idso et al. (1975a). They use three categories: "the visible, or shortwave, region; the thermal, or longwave, region; and the radar, or microwave, region." To these the author would add the passive gamma radiation technique, although this is limited to low-flying aircraft as opposed to potential satellite instrumentation. (Jones, et al, 1973.)

The short wave radiation techniques primarily rely on spectral reflectance properties of the soils. Idso et al. (1975b) showed that a normalized albedo could be correlated with volumetric water content of a soil. The results showed that for the uppermost 2 cm of the soil, a linear relationship could be obtained. This however was for a smooth, bare surface.

The thermal analyses are based on the generally accepted concept that a cool soil is a moist soil and a warm soil is a dry soil. This concept can be extended by using the thermal inertia as well as surface temperatures. Idso et al. (1975c) have used the concept of thermal inertia on four separate soils and found an acceptable correlation moisture tension (i.e., pressure potential).

Moore and Haertel (1975) have shown (using Skylab data) that thermal IR data can be used to develop regression equations for prediction of soil

moisture in fallow fields for the top 30 cm of soil with a correlation coefficient as large as 0.95. Similarly, with variable crop cover the correlation coefficient was as large as 0.74. From this study they have concluded, "Thermal data provided a better estimate of soil moisture than did data from the reflective bands." They further concluded, "Surveys of areas of high soil moisture can be accomplished with space altitude thermal data."

Another approach is the use of microwave "brightness temperature." Schmugge et al. (1975) reported on satellite microwave experiments to monitor relative amounts of soil moisture using the ESMR (electrically scanning microwave radiometers) on the Nimbus 5 satellite. Three areas were considered: the Illinois-Indiana study area, the Mississippi River Valley, and the Great Salt Lake Desert. Brightness temperatures from the 1.55 cm thermal band were used for the analyses along with antecedent rainfall data. The data obtained were promising, but the system is limited to bare ground since vegetation absorbs microwave radiation emitted at 1.55 cm from the soil. It must also be recognized that the Nimbus 5 satellite ESMR would allow for only 10 to 25 km resolution. Despite these limitations the approach appears to have promise.

The approaches thus far discussed are primarily applicable to bare ground, with the possible exception of the work of Moore and Haertel (1975), and even then problems were encountered. All techniques discussed above, when based on satellite data, are also subject to the problems of cloud cover.

A non-satellite remote-sensing technique for soil moisture that is only slightly affected by vegetation is the passive-gamma system. Soil moisture in the top 8 to 10 cm of the soil mantle has been one of the elements which must either be defined or assumed when using the passive-gamma system to monitor the water equivalent of a snowpack (Peck et al. 1971, Jones et al. 1973, and Loijens and Grasty 1973). When there is no snowpack present the same concepts can be used to estimate areal soil moisture from low-flying aircraft. This has been demonstrated with success near Luverne, Minnesota (Feimster and Fritzsche 1975), and near Phoenix, Arizona (Feimster, Fritzsche and Jupiter 1975). The long line averages (8 to 16 miles) agree very closely with the ground

truth; however, the mile-by-mile averages can vary as high as 10 or 11 percent, expressed as a difference in the airborne estimate and the ground-truth soil-moisture percentages. This system appears to hold promise when the soil-moisture resolution requirements are on the order of a few miles.

At the present time there does not appear to be a satellite system capable of collecting all the soil-moisture data desired. Admittedly the Landsat C and follow-on programs with the thermal band will give tremendous advantages based on the work of Moore and Haertel (1975). Even with this the major limitation in any operational system appears to be the lack of ability to "see through" the vegetation. The vegetation problems should receive research attention to help meet operational requirements.

In summary, there are not yet systems which will provide the requirements set forth by the Inland Waters Group in the 1974 Summer Study. There have been however, some very promising results.

4. <u>A Look to the Future</u>

At the outset, the author is still of the opinion that remote sensing of soil moisture has and will continue to have a high relative benefit. There appear to be two distinct scales on which such remote sensing would be conducted--the large regional scale and the local scale. (In some cases they would overlap.) Both scales are important to water resources management and planning; however, each scale brings about problems of resolution and data delivery schedules.

For the local and possibly regional scale, there will be those who want a 1-acre-or-less spatial resolution. An example of a local scale mission would be to assist in an irrigation district's irrigation scheduling. One would want field-by-field estimates to be of maximum value. In many cases on the regional scale, resolution of a few kilometers may be quite satisfactory. A regional scale mission might be to assess crop production in non-irrigated areas as a function of soil moisture. Obviously this would require less resolution capabilities than the previous example of a local scale mission. The point is that remote sensing of soil moisture will mean different things to different people. The same applies to the delivery schedule for the data. Soil-moisture data are time dependent, and the economies of collection must not be offset or negated by inappropriate delivery schedules for the data.

The author would hope that with the planned Landsat follow-on, further advances in the remote sensing of soil moisture can be made. Particular attention should be given to the various estimation techniques so that these can complement the satellite obtainable information. Similarly, some reliance should be placed on satellites other than the Landsat series--if they have instrumentation that would complement the soil-moisture program, then it should be used insofar as possible. It is the author's opinion that all possible sources of information should be utilized to help solve a problem such as remote sensing of soil moisture rather than attempting to combine all requisite elements into one package.

One problem at the present time with Landsat data is the restrictions of cloud cover, vegetation and a nine-day time interval. Irrigation scheduling, flood forecasting, and reservoir management, which carry potentially large benefits, may be realized only with more frequent sample times. To achieve these benefits one may need to seriously consider a geo-synchronous satellite.

Thoughout this discussion, there has been the tacit assumption that there is indeed a demand for soil-moisture data. Inventories of data requirements would no doubt bear this out, but one must also look at what is being done at the present time. Much of the current irrigation scheduling is being done with tensiometers or in-place soil-moisture sensing devices. Despite soil-moisture variations in a field, a few gravimetric samples can tell one a considerable amount about the field. The role of the remote sensing of soil moisture must then be that of doing the job better, and/or more economically than is now being done. No doubt a total continental survey of soil moisture would turn up new information, but routine determination of soil moisture on a repetitive task will be confined to certain specific areas.

D. GROUNDWATER

1. Background

In the first 2 years after launch of Landsat 1 (1972 to 1974), interpretations for ground-water occurrence mostly were made manually on standard-product images. General principles of photograph interpretation

were used to detect and classify regional landforms, drainage patterns, geologic structures and lithologies, and other image patterns, defined mostly by tone and texture. A number of major lineaments (presumed to indicate joints and faults), arcuate to circular features and other geologic structures were discovered by these methods; several studies then were begun to determine the significance of the interpretations. A majority of the features were shown to be of geologic origin and thus to have potential importance for ground-water occurrence. It gradually became clear that Landsat data could be an important new tool for areal studies of subsurface water resources.

The trends in the next 2 years after launch (1974 to 1976), have been toward using Landsat data as a routine tool to (1) aid in solving specific problems, such as those of water supply or ground-water pollution, (2) plan field work or reduce the need for field work, and (3) obtain new information that would be difficult or costly to obtain on the ground. Thus, Landsat data presently is being used to detect lithologies and structures favorable for ground-water occurrence, to delineate at least parts of the limits of aquifers, and to obtain information on the operation of aquifers.

The need to obtain additional information from Landsat data has created an impetus for working closer to the resolution limits of the multispectral scanner than is possible with standard-product imagery and for utilizing more of the spectral sensitivity of the scanner than is possible with film products. Thus, the present trend is toward digital processing of Landsat data on magnetic tapes, both to generate enhanced images for manual interpretation and to classify and delineate (by symbol or color coding) hydrologically significant features.

About eight Federal Bureaus, 20 State geological-survey or water-resource agencies, 30 Universities, and several consulting engineering firms are using Landsat data for the study of problems involving or impacting ground-water problems and resources. In most cases, however, these are either local studies or studies that involve only one aspect of the subsurface-water resources of an area. The use of Landsat data

for ground-water studies is increasing, but this use presently involves a relatively low level of effort.

Total present use of Landsat data for subsurface-water problems is estimated at 10 man years per year. In order to properly utilize the information content of Landsat data in ground-water studies that are underway at the present time, this effort would have to increase to about 30 man years per year. The main reasons for a reluctance to fully utilize Landsat data are (1) psychological, (2) lack of adequate training, (3) limited availability of digital processing, and perhaps (4) high costs of digital processing.

Water historically has been a low value commodity; studies of ground-water resources almost always have been government funded and have had minimal budgets. The man in the field is reluctant to change the established conventional methods of obtaining information, because his project cannot afford extra costs and wasted time. It is significant, however, that several hydrologists with considerable training and experience in the interpretation of remote sensing data have remarked that they could not conceive of beginning an areal study of water resources without first evaluating the information content of aerial photographs and Landsat images.

The purposes of this section are (1) to describe the present state-of-the-art in using data from Landsat 1 and 2 to obtain information on subsurface water resources, and (2) to speculate on the utility of data from Landsat follow-on. Thus, the implications of a thermal infrared channel on Landsat C are not considered, nor is the potential utility of data from Heat Capacity Mapping Mission A and from Seasat A.

Landsat data may be used to (1) detect and delineate some aquifers, which occur either at land surface or at depth, (2) detect some recharge and discharge areas, as well as study seasonal and annual variations in the amounts of recharge and discharge, (3) detect and delineate geologic structures, which may affect the occurrence and movement of ground water, and (4) estimate increases in ground-water use, especially by monitoring increases in areas of irrigated crops and fish farming.

2. Role of Current Landsat Program

a. Occurrence and Limits of Aquifers. The criteria used to detect surface and near surface aquifers differ from those used to interpret the occurrence of deeper aquifers. Topographic relief, geologic structures, landforms, snowmelt patterns, anomalous soil moisture patterns, and vegetation types and times of growth all may be clues to the detection of shallow aquifers. Geologic structures are the only indicators of deeper aquifers.

For the purposes of this report, the term shallow aquifers is limited to unconsolidated deposits of sand and gravel. Many other types of rocks occur at shallow depths, but fracture porosity generally is more important than intergranular porosity in determining the permeability of these formations. Although fracture porosity occurs at both shallow and deeper depths, it can be discussed more easily as a type of deeper aquifer. Tubular basalt flows are a special case and are described in the section on ground-water discharge.

b. Shallow Aquifers. Many well-sorted sands and gravels, which outcrop at the land surface or subcrop near the land surface, form good aquifers below the water table. In almost all cases, well-sorted sands and gravels represent fluvial deposits (exceptions are beaches, beach ridges, and other dunes), either in the form of stream channel and valley fills or as alluvial fans and bajadas. Keys to the detection of these aquifers on Landsat images thus can be listed:

(1) Characteristic Shape or Form

- Stream valleys (particularly broad and shallow valleys).
- Topographically low strips representing underfit valleys.
- Natural levees in wetlands and other flat areas.
- Meander loops defining locations and thicknesses of point bar deposits.
- Meander scars in lowlands and arcuate dissection of upland areas adjacent to lowlands. Oxbow lakes.
- Braided drainage channels and scars.
- Alluvial cones and fans; coalesing fans.

(2) Patterns

- Snowmelt; anomalous early melting of snow and greening of vegetation in areas where water table is at or near land surface.

TABLE II-5
APPLICATION ASSESSMENT TABLE

Application:

Aquifers

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Near Surface Aquifers		
Topographic Relief.	Stereo coverage.	Negative.	
	Low sun angle.	Negative.	
Geologic Structures.	Patterns.	Better than Landsat 1 and 2.	
	Landforms.	Poorer than Landsat 1 and 2.	
	Tones.	Better than Landsat 1 and 2.	
	Textures.	Do.	
Landforms (aquifer inference).	Patterns (tones, textures, shapes).	Somewhat better than Landsat 1 and 2.	
Snowmelt patterns.	Patterns and tones.	Better than Landsat 1 and 2.	
Soil Moisture.	Patterns (tones and vegetation).	Do.	
Vegetation types.	Tones and textures.	Do.	
	Deeper Aquifers		
Landforms.	Shapes.	Poorer than Landsat 1 and 2.	
	Tones, textures, shapes, and patterns.	Somewhat better than Landsat 1 and 2.	
	Recharge Areas		
Landforms and relief.	Low sun angle, patterns.	Negative.	
Drainage patterns.	Shape and pattern.	Somewhat better than Landsat 1 and 2.	
Lineaments.	Relief, tones, textures.	Better than Landsat 1 and 2.	
Lakes and sinkholes.	Tones, patterns.	Do.	
Vegetation types.	Tones, textures, patterns.	Do.	

- Elongated lakes; sinuous lakes; alinements of lakes and ponds. Alined ponds or other low areas may be remnants of a former stream valley. Many closed depressions had overflow channels during past wetter climates.

(3) Image Tone

- Soil type; fine grained soils commonly are darker than coarse grained.
- Anomalous high or low soil moisture; wet soils are darker than dry soils. Tone of sand and gravel depends on position of water table.
- Type and species of native vegetation; this is a complex situation but vegetation generally is well adapted to type of soil, drainage characteristics, and period of saturation of the root zone.
- Anomalous early or late seasonal growth of native vegetation in areas where water table is close to land surface.
- Land use; native vegetation may occupy low areas because of periodic flooding, whereas uplands are used for agriculture, for example.

(4) Image Texture

- Type and species of native vegetation; uniform or mixed types.
- Dunes; contrast between bare sands on topographic highs and native vegetation in low (wetter) areas.
- Land use: mixed, representing local differences in topography, soil type, or drainage characteristics, for example.

Features that have a characteristic shape or form can be used to detect shallow aquifers with good relative confidence. Best results generally are obtained with manual interpretation of a band 7 or color composite image. A low sun angle (November 15 to January 31 in the northern hemisphere) is desirable to necessary. In areas with dark colored soils, a light snow cover enhances the topographic shadowing produced by a low sun elevation; elsewhere snow may obscure fine topographic detail. The main problem is the relatively low resolution of the Landsat scanner--only parts of the significant features can be detected and delineated. In some areas, Landsat images can be used to select locations for test wells. In other areas Landsat images are best used to select locales which can be examined in more detail on aerial photographs or on the ground.

Large regional patterns commonly are seen best on Landsat images. Bands 5 (for lakes with emergent vegetation), 6, or 7 images generally are best for detection of patterns formed by lakes and ponds. Color composite images are best to study snowmelt patterns. Patterns have a lower relative confidence than landforms as indicators of shallow aquifers. Also, local patterns that indicate ground-water springs generally are below the resolution limits of the scanner.

Unless ground truth information is available, image tones and textures have the lowest relative confidence as indicators of shallow aquifers. Nevertheless, in some cases tones and textures form patterns that, in turn, are distinctive indicators. Digital processing of magnetic tapes on an interactive man and machine system has proven useful for enhancement and classification of Landsat spectral data. An alternative is manual interpretation of either a color composite image of bands 4, 5, 6, and 7 images. Textures generally must be detected and delineated manually, although the complex spectral signatures of some areas are distinctive. The main problem with tones and textures is that an area underlain by a shallow aquifer may show a variety of tones; no single indicator occupies an area large enough to form a diagnostic pattern. An underfit valley in early spring, for example, may have some areas that show the dark tones of high soil moisture abutting other areas that have an anomalous early growth of native vegetation. Such cases can be enhanced by machine processing, but the significant pattern generally must be detected visually.

Early spring and fall images generally are best for detection of differences in soil type, soil moisture, and type and species of vegetation. Usually, this is from April 1 to May 30 and September 1 to November 15. The best time varies from one year to another as well as by location and because of local conditions and indicators. It may be possible to evaluate the annual situation with a color composite image. In the Eastern United States, for example, a Landsat spring calendar could be devised:

(1) Plowing of agricultural areas begins.

(2) First deciduous trees turn green.

(3) Plowing completed.

(4) Most deciduous trees are green.

(5) Native brush and grass begin to grow.

. Moist but well-drained areas.

. Wet areas.

(6) Crops produce vegetation hues.

(7) All vegetation growing vigorously.

Other times of year are important locally. Winter images are best for detection of shallow aquifers near the Louisiana coast, for example.

Boundaries that are gradational on the ground generally are sharper on Landsat images. Hydrologically significant patterns, tones, and textures generally can be delineated most easily on Landsat images. On the other hand, more detail is visible on aerial photographs.

c. Deeper Aquifers. For the purposes of this report, the deeper aquifers include all consolidated rocks, where fracture porosity is more important than intergranular porosity, plus the deeper aquifers of sand and gravel.

The close relationship between rock fractures and ground-water movement in consolidated rock terranes has been recognized since at least the early 1900's. However, the significance of fracture traces and lineaments on aerial photographs as indicators of joints and faults generally was not discussed in the literature until the 1950's. Studies suggesting the application of fracture traces and lineaments to ground-water prospecting soon followed.

The significance of lineaments visible on Landsat images to occurrence and movement of ground water in consolidated rocks has not been widely or extensively studied. Nevertheless, some lineaments have been determined to correspond with fault and fracture zones. Anomalously large well yields occur along some of these lineaments; although this fact has very little significance by itself, logical reasoning suggests that only the largest fracture zones (and presumably the most hydrologically significant) should be visible on Landsat images. There is good reason, therefore, to believe that locations on lineaments, which can be detected on Landsat images, will produce larger than average well yields.

In unconsolidated rock terranes, analysis of the fracture patterns detected on aerial photographs has been used as a prospecting tool for petroleum traps since at least the 1950's. Since 1972, a number of lineaments, defined mostly by drainage patterns, have been detected on

Landsat images in (1) coastal plain sediments, (2) alluvium-filled valleys, and (3) glaciated terranes. Also, several studies have reported that lineaments were continuous from areas of hard rocks into areas of unconsolidated rocks. These facts suggest that lineaments reflect fractures in the underlying bedrock and that these fractures have propagated upward to land surface through unconsolidated materials (more than 3,000 meters of such materials in the Gulf Coast region).

The facts also suggest that the forces, which cause fractures, have been active over long periods of geologic time. Several scientists, reasoning independently, have proposed informally that fractures controlled the positions of many rivers and streams (and thus the locations of coarse-grained fluvial deposits) at the times that the unconsolidated materials were being deposited (in the same manner that fractures control some present streams, since most lineaments are formed by drainage patterns). This hypothesis has not been widely tested, but it provides a potentially important interpretation key for Landsat images: coarse-grained aquifers should occur at depth beneath lineaments visible on Landsat images in glaciated terranes, alluvial valleys, and coastal plains.

Conditions favorable for the detection of lineaments are similar to those for detection of landforms. Thus, stereo viewing or a low sun elevation is helpful to necessary for best results. Bands 5 and 7 images as well as color composite images should all be examined, if time permits. Manual interpretation is necessary because only the human eye can fuse short, discontinuous, straight-line segments and perceive a lineament. Machine enhancements, particularly noise removal, density stretching, and fine detail enhancement may aid lineament detection but are not essential.

d. Recharge Areas. Recharge areas can be detected on Landsat images by analysis of topographic relief, landforms, lineament locations, drainage textures and patterns, water-filled lakes and sinkholes, and vegetation patterns.

Recharge commonly occurs over the entire area where an aquifer is at or near land surface. Nevertheless, some points or areas are important as major centers of recharge; detection and identification of these centers contributes to an understanding of aquifer limits and operation.

The important factors in aquifer recharge are amount of available water, period of time that water is available for recharge, topographic slope, soil permeability (both surface soil and subsoil), and moisture content of the unsaturated zone at the time of recharge (soils must be saturated before recharge can reach the water table).

If soil permeabilities are equal, more water runs off the surface of steep hillsides (and less water percolates down to the water table) than on flat or slightly sloping areas. In addition, coarse-grained alluvial and colluvial materials commonly occur near the base of slopes. A consideration of these conditions shows that all factors are favorable for important centers of recharge near the bases of hills and mountain ranges:

(1) More water is available (that which falls as precipitation plus that which moves downslope over the land surface).

(2) Water is available for relatively long periods of time (the period of precipitation plus the period for overland flow).

(3) Slopes are shallow.

(4) Soil permeability is relatively high.

(5) The relatively large volume of available recharge should achieve saturation of the soils.

If everything else is equal, more recharge will occur where sands and gravels crop out at land surface. Thus, most of the landforms that indicate near surface aquifers also are indicators of important recharge centers.

Fracture zones commonly have relatively high permeabilities as compared to adjacent areas. Thus, fractures can serve as sinks or traps for overland flows and commonly are major centers of recharge. The detection and mapping of lineaments can contribute to an understanding of aquifer recharge.

Drainage textures commonly are indicators of surface materials. A fine textured drainage reflects either fine-grained or more consolidated materials whereas coarse textured drainage reflects either coarse-grained or less consolidated materials. Both grain size and amount of consolidation affect permeabilities. Coarse and fine drainage textures are relative terms in any area, because texture also depends on other factors, such as land cover, slope, and intensity of precipitation. Drainage

textures are developed best in arid areas and can be seen on many Landsat images of these areas' drainage density (length of stream channel per unit drainage area) is a similar indicator that can be measured in humid regions.

The theory of drainage density is that the number and length of stream channels in any area are determined by the size of the mean annual flood. One factor in flood size is the permeability of surface materials: if more water percolates to the water table, less water runs off the land surface; floods are smaller and there are fewer and shorter stream channels in this area. Drainage boundaries can be delineated on topographic maps and transferred to Landsat images. The number and length of stream channels that are visible on Landsat images depend on topographic relief, land cover, and sun elevation as well as on size of channel. Nevertheless, drainage density as determined on Landsat images may be related to surface permeability in some areas.

Drainage patterns are closely related to drainage textures in arid regions. Thus, a fine textured drainage generally consists of closely spaced parallel, sub-parallel, or pinnate stream patterns, whereas coarse textured drainage tends to be more of the dendritic type.

Sinkholes, playa lakes and other closed depressions can be important centers of recharge. Unless they fill to overflowing, all the water that falls or flows into them must percolate downward, evaporate, or be transpired by plants; no water can run off the land surface to streams. The bottoms of some depressions are sealed by clay and other fine-grained materials. The depressions that are most important as recharge centers are those that drain rapidly after heavy rains. Water-filled depressions can be detected and monitored on sequential Landsat images.

In the Western United States, most ground-water recharge comes from melting of the mountain snowpacks in the spring months. The blooming desert at this time of year reflects the relatively high soil moisture conditions, which accompany the recharge process. The rapidly growing and relatively dense stands of vegetation produce subtle but distinctive hue on color composite Landsat images.

The best form of Landsat data and the best type of procedure for detection and analysis of topographic relief, landforms, and lineaments

have been discussed previously. Band 7 images are best for manual detection of water-filled depressions, but area measurements may be more accurate on band 6 images. (Water areas are so black on band 7 images that they tend to cover relatively larger areas on the image than on the ground.) Digital processing simplifies area measurements and thus the determination of changes in water area on sequential Landsat scenes. The subtle hues that indicate relatively dense desert vegetation may be detected manually on good quality color composite images, but delineations can be made with more confidence after digital enhancement or classification.

e. Discharge Areas. Ground water generally moves from topographically high areas toward points of discharge in rivers and streams. In consolidated rock aquifers, the largest amounts of ground water generally are available close to points of discharge. Thus, location of points, lines, and areas of ground-water discharge aids in defining aquifer limits, in understanding aquifer operation, and sometimes in locating areas of ground-water abundance. Discharge areas are indicated by flowing streams during periods of low flow, by lineament locations in topographically low areas, by the continuing healthy growth of vegetation during droughts, and by areas of water use, such as cities and irrigated fields.

Near headwaters, overland flows cease a few hours to a few days after the end of precipitation. The continuing flows of streams in these areas are proof of ground-water discharge. Similarly, if the ratio of channel depth to width is constant, the downstream increase in width of a stream is evidence of additional ground-water discharge.

Many streams are too narrow to be seen on Landsat images, but moist to water-saturated soils are commonly adjacent to the channel; the combination of water in the streams and wet soils may form dark toned strips on bands 6 and 7 and on color composite images. In semiarid regions, the darkest center part of this strip gradually increases in width downstream.

Fracture zones commonly form conduits for ground water in consolidated rock formation. The most likely points for discharge of ground water from fracture zones are the topographically lowest points. Theoretically, at least, ground-water discharge should be expected

where lineaments cross valleys. If the lineament crosses several valleys, the fracture zone may carry water from a smaller, topographically higher valley to a larger, deeper valleys, (beneath surface drainage divides).

In arid regions, areas of dense, healthy vegetation indicate ground-water discharge (by streamflow if the water table intersects land surface or by evapotranspiration if the water table is below land surface). These are the areas occupied by phreatophytes and other forms of riparian vegetation. Similarly, distinct species and types of vegetation occur in the wetlands of humid regions. Some wetlands are predominantly recharge areas, but others are areas of ground-water discharge.

In humid regions, areas of ground-water discharge may be indicated on Landsat images by patterns formed by the dark tones of wet soils in early spring, by anomalous early or late spring growth of vegetation, and by anomalous continuing growth of vegetation during dry periods in late summer and fall.

The ground water withdrawn by pumpage may be an important factor in the operation of aquifers and is discussed in the section on water use.

Some basalt flows contain tubes which serve as conduits for ground water. Ground-water discharge occurs at the edges of the outcrop area, generally on hillsides or in valleys. Basalts at land surface commonly can be recognized on Landsat images by dark tones on bands 4, 5, 6, and 7 and by dark (generally gray or bluish gray) hues on color composite images. In arid regions, areas of discharge are indicated by vegetation patterns. In developed regions, such as the Snake River plain of Idaho, discharge may be mainly by pumpage for irrigation.

Areas of ground-water discharge may be interpreted manually or enhanced and classified by digital processing. Dark soil tones may be detected on color composite images but generally are easier to delineate on bands 5 and 7. Color composite images in spring, late summer, and fall are best for detection of anomalous vegetation patterns. Digital processing generally is necessary for classification and delineation of specific vegetation types and species.

f. Geologic Structures. Geologic structures, such as faults and folds, commonly affect the occurrence and movement of ground water and

thus may also affect the chemical quality of ground water. A number of previously unknown fracture zones and folds have been found on Landsat images. The hydrologic significance of the detected structures has not been widely tested, but logical reasoning indicates that the structures should be hydrologically important. Two examples can be described.

The Beech Grove lineament in central Tennessee is about 165 km long and 2 to 6.5 km wide; it has a topographic expression in this limestone terrane and is formed by the alinement of nine separate stream valleys. The lineament apparently consists of a group of closely spaced parallel fractures, but the movements that caused the fractures did not produce significant displacements. It has been hypothesized that ground water moves along the lineament from some small streams at relatively high altitudes to nearby larger streams at lower altitudes. This hypothesis has been tested but not completely confirmed by test drilling.

The Jonesboro lineament extends from Newport, Arkansas east-northeastward across unconsolidated sediments of the Mississippi embayment region nearly to the Mississippi River, a distance of about 135 km. It is formed by the Newport re-entrant, by lateral displacements of the channels of three southward flowing river, and by the lateral displacement of Crowleys ridge (an erosional remnant that separates the present alluvial valley from an abandoned valley of the Mississippi River) at Jonesboro, Arkansas. South and east of the lineament virtually all ground-water pumpage is from Eocene aquifers, a sequence of sands about 300 meters thick. North of the Jonesboro lineament the Eocene aquifers are little used, reportedly because the water is of poor chemical quality. The fault or fold that produces the lineament may inhibit the circulation of ground water in the Eocene aquifers of northeast Arkansas and southeast Missouri.

A number of other linear, arcuate, and circular features have been detected on Landsat images. Circular features are relatively common in terranes of volcanic rocks and unconsolidated materials. Some circular features apparently are related to domes and geologic basins. In areas of sedimentary materials, if the structures are deep seated and geologically old, they could have affected sedimentation patterns in the

past; thus they may explain local variations in aquifer permeability.

The hydrologic significance of circular and arcuate features as well as the dominent trends and patterns of lineaments have not been determined.

Bands 5 and 7 or color composite Landsat images are best for detection of geologic structures. Manual interpretation is desirable to necessary, although enhancements produced by digital processing can be helpful. Spring or Fall imagery is desirable for the detection of structures formed by vegetation patterns. On the other hand, a low sun angle is best for detection of significant topographic forms.

The number and size of geologic structures that are detected on remote sensing imagery of any type are directly related to the scale, areal size, and resolution of the images. Thus, some features detected easily on aerial photographs are too small to be visible on Landsat images, whereas some regional structures, detected on Landsat images because of the large areal coverage, are either obscure or visible but not obvious on aerial photographs.

g. Water Use. Large amounts of ground water are used for irrigation throughout the United States. In the dry western States, fairly accurate records are maintained of the amounts of water pumped and distributed. The main need in this area is to predict future water use for management purposes. In the humid East, on the other hand, few irrigation records are kept by individual farmers. One need in this area is to obtain better estimates of irrigation pumpage to correlate with water-level trends. In particular, very little information is available on the short-term fluctuations in water use--from one month to another and from one growing season to the next.

The need for better data on irrigation use is increasing in the eastern States. In Mississippi, for example, rice production covered an average 140 square km and had never exceeded 200 square km before 1974. Production increased to 460 square km in 1974 and to 790 square km in 1975. Intentions are 810 square km in 1976. Almost all rice irrigation is from ground water, and average water use is 1.2 meters over a 120-day growing season. This means that ground-water pumpage for rice alone increased from an average 0.17 cubic km before 1974 to an estimated 0.99 cubic km for 1976. Assuming a 25 percent aquifer

porosity and no recharge, the 1976 pumpage will lower the water table by about 5 meters beneath the area of rice production or about 0.5 meter over an entire five county area (where rice is grown) in western Mississippi.

By identifying specific water uses such as irrigated crops or fish farms on Landsat images, areas can be measured, and amounts of water use can be estimated. These data then may be used to estimate changes in pumpage, to predict water needs, and to anticipate problems caused by increasing pumpage. Identification of areas of water use can be done manually on Landsat images with the aid of historical records. However, classification and measurement of areas is best done by digital processing.

h. Limits to Information Content. The main limits on the information content of data from Landsat 1 and 2 are scanner resolution, 4-band spectral signatures, repeat cycle of 18 days, sun elevation angle, and lack of stereo coverage.

A better resolution would permit detection of many more lineaments, small folds, water-filled lakes and ponds, and small landform, soil, and vegetation patterns. More information could be developed per unit area and Landsat data would be more useful for studies of small areas. At least some of this information, however, would be obtained at the expense of overlooking broad regional patterns that can be seen on images from Landsat 1 and 2.

Four scanner bands produce spectral signatures that commonly are inadequate for machine classification of hydrologically significant soil and vegetation types. Additional bands would improve the capabilities of digital classification but would increase processing and information costs considerably. Also, unless a specific best band could be identified for a specific information need, the costs of digital processing might be necessary; manual interpretation would be more time consuming and less practical.

Some surface features that are indicative of subsurface conditions occur for only short periods during a year. A number of sinkholes and ponds drain dry a few hours to a few days after the end of precipitation. Snowmelt, emerging vegetation, and soil-moisture patterns may be significant for periods of only 2 days to 2 weeks. Although Landsat 1 has

been producing images for nearly 4 years, the maximum information on landforms in eastern South Dakota can be obtained only from images on January 1, 2, and 3, 1973. In many areas of the country, there is not yet a good sequence of Landsat images to show the emerging patterns of vegetation in the spring and the patterns of mature or dormant native vegetation in the fall.

The lack of overlap on adjacent Landsat images is a handicap for detection of hydrologically significant landforms. Images from November through January do have a low sun illumination angle that produces topographic shadowing and enhances landforms. Nevertheless, this illumination angle is still too large for topographic detail in relatively flat terranes at the lower latitudes. Additional information would be possible with either stereo sidelap or coverage at earlier or later times of day.

3. Impact of Landsat follow-on

The characteristics of the thematic mapper on the proposed Landsat follow-on will not change the principles that are used to interpret data from Landsat 1 and 2. The characteristics also should not appreciably change the list of surface features that are significant for ground-water interpretations, using existing data. More data in more spectral bands with better resolution will permit:

(1) More detailed interpretations of tones, textures, and patterns of vegetation and soils. Detection of numerous smaller patterns. Development of more information on the significance of the patterns for ground-water occurrence, recharge, discharge, and water use.

(2) If sun illumination angles are equal, detection of more topographic detail, detection of smaller and more numerous geologic structures, and detection of many more hydrologically significant landforms.

(3) Detection of more detail in snowmelt and soil-moisture patterns. Detection of more hydrologically significant features in these patterns.

(4) Detection of smaller lakes and ponds and more patterns formed by shapes and alinements. More accurate measurements of water area and a better understanding of aquifer recharge.

(5) Delineation of water in small streams in headwater areas and location of more areas of aquifer discharge.

(6) Detection of more and smaller lineaments. More potential locations for large well yields in consolidated rock terranes. A better understanding of the patterns formed by dominant lineaments trends and by intersecting lineaments.

(7) A better definition of drainage patterns, of the geologic structures indicated by these patterns, and of the hydrologic significance of the patterns.

(8) More accurate measurements of drainage density and thus of surface permeabilities in unmapped areas.

(9) Easier detection and classification of drainage textures in arid regions.

(10) More accurate measurements of stream-channel width and thus better location of reaches of streams where aquifer discharge occurs.

(11) A more accurate determination of the types of outcropping rocks and a more accurate interpretation of the water-bearing characteristics of the rocks.

(12) A more accurate determination of crop type and thus better estimates of water use and water needs.

(13) Detail by which hydrologically significant surface features can be distinguished more easily from those that are not significant.

(14) A better definition of aquifer limits and a better understanding of aquifer operations.

(15) A greater variety of formats for manual interpretation.

(16) Improving the capabilities and results of digital processing.

(17) An additional impetus to the trend for digital processing.

The high resolution thermal infrared band 6 on the thematic mapper should provide information on rock types and soil moisture patterns. Interpretations will provide information on locations of shallow aquifers, recharge and discharge areas, water use (irrigated fields), and perhaps geologic structures. These data should be most useful in the dry western States and in all agricultural areas during the spring and fall.

The higher sun-elevation angles of Landsat follow-on will produce less enhancement of landforms, the interpretations of which have a relatively high degree of significance for ground-water information.

An increase in coverage frequency will increase the chances of obtaining good quality, cloud-free Landsat images at times that are important for ground-water interpretations. Also, it will shorten the time needed to obtain a sequence of Landsat scenes showing emerging and developing patterns of vegetation and soil moisture.

The speed of data delivery will not be important except for studies that already are underway at the time of launch.

The man in the field probably will not make full use of the data from Landsat follow-on in the first few years after launch, because of the problems described previously. However, research scientists in universities and government are ready now for an increased spectral and spatial sensitivity. The information content of data from Landsat 1 and 2 has been fairly well evaluated. The higher information content of data from Landsat follow-on should result in an accelerating use of satellite data in routine field operations. With data from only Landsat 1, 2, and C, use should increase to about 15 man years per year by 1985. With Landsat follow-on, use should reach more than 20 man years per year by the same date. A corresponding increase in the number of hydrologically significant discoveries can be anticipated.

4. Summary

Conventional techniques to locate and delineate aquifers always use well information (obtained by inventory or test drilling) and also may include an analysis of base streamflows, surface geology and geophysics. About 175 man years per year at a cost of $7 million are spent on the inventory and management of underground aquifers.

Data from Landsat 1 and 2 presently are being used to detect lithologies, structures, and landforms favorable for ground-water occurrence; to delineate at least parts of the limits of aquifers and to obtain information on the operation of aquifers. Some of this information is new and would be difficult or costly to obtain on the ground. Other information is used to plan field work or reduce the need for field work (the most expensive phase of a ground-water study) and to solve some site problems of water supply.

The costs of using data from Landsat 1 and 2 ar estimated at 10 man years per year and 0.4 million dollars; the benefits resulting from this use are estimated at $1 million. Thus the present level of effort results in a net cost savings of $0.6 million per year. Furthermore, the cost/benefit ratio of using Landsat data continues to decrease, as the data are utilized more efficiently.

The characteristics of the thematic mapper on the proposed Landsat follow-on will not change the principles that are used to interpret data from Landsat 1 and 2 and will not appreciably change the list of surface features that are significant for ground-water interpretations. More data in more spectral bands with better resolution will permit an increase in the amount of ground-water information, which can be obtained from the data.

Costs of using Landsat data (including data from Landsat follow-on) are expected to increase to $0.8 million (at 1976 costs) by 1985. Benefits should increase to about $2.5 million. Cost/benefit ratios will be higher than this for about two years after launch of Landsat follow-on, however, as scientists learn to use these new data efficiently.

Remote sensing generally will not provide the information on subsurface water supply that is needed for watershed modeling and systems management; the only exception is the detection and delineation of some aquifer limits, which also form model limits.

E. LAKE AND RESERVOIR MAPPING

1. Background

Inland lakes and reservoirs constitute one of our greatest water resources. Lakes and reservoirs serve as sources of recreation, navigation, water supply, flood control, water purification, mediums of biological growth, groundwater recharge, and others. These water bodies are dynamic and vary with landscapes, climate, activity of man, and time. A reservoir is commonly referred to as the water impounded by any artifical barrier. The definition of a lake varies with the location and background of the people in the region. A basin termed a lake in the upper midwest may be termed a pond in the southeast. A continuum of sizes, shapes, occurrences of vegetation, depths, and other characteristics occurs. Therefore, for the purpose of the

following discussion, a lake will be termed water standing in a natural basin without definition as to its size, characteristics, and value. In this definition, the lake could have been formed by different processes including tectonic, volcanic, glacial, wind, streams, and many others.

Reservoirs were formed by man and therefore contain the inadequacies created by man. Underdesign of structures, permeability of the bottom of the reservoir, effects on the complex groundwater regime, and many problems can occur. For example, the requirement for continued analysis of dam safety was nationally recognized during the loss of life and property associated with the flood catastrophies in West Virginia and South Dakota. This led to the national inspection of dams program directed to the Secretary of Army.

Our lakes and reservoirs are continually filling with sediment and organic debris by natural succession. However, some evidence of increased sedimentation associated with man's manipulation of the landscape has been illustrated. In either case, one must realize that the lakes are subject to change with age and are not permanent. What once was a lake of considerable value in water storage and supply may now be of value only to recreation. Many of the lakes in the Northern Great Plains are changing rapidly with the greatest alteration caused by the deposition of sediment creating shallower depressions which respond readily to small changes in nutrient contents. At some time in the future, these lakes will be non-existent and natural drains will have developed integrating the surface drainage of the landscape. If water impoundments are to occur, they will have to be man made or at least man managed. The understanding of the appropriate actions of man in either deceleration or acceleration of these processes and their resulting effects is limited because of the lack of reliable information.

The use of remote sensing in gaining the understanding of our natural landscape containing lakes and in the positioning and designing of man-made water impoundments is definitely an advantage. This involves the use of repetitive, synoptic, spectral, and spatial information as obtained via imaging systems and the use of satellite communications capabilities in the ground data collection systems. Many federal, state, and local agencies have and will continue to initiate evaluation and uses of these data.

APPLICATION ASSESSMENT TABLE

TABLE II-6

Application:

Lake and Reservoir Studies

<u>Information Needs</u> (ground features to locate and evaluate)	<u>Parameters</u> (kinds of evidence in imagery, for "information needs")	<u>Feasibility</u> (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	<u>Remarks</u> (evidence experience problems, etc.)
Many Parameters - size, shape, volume.	Spatial, spectral, temporal data.	Adequate for spatial and spectral needs to measure size, shape and volume.	There is a need for quantitative data. This can be obtained for spatial data.
Chemical Constituents Physical Constituents Biological Constituents	Patterns, tone, texture.	Probably adequate to identify a few physical and biologic constituents (sediment and algae). Probably inadequate to identify chemical constituents and their concentration.	Much ground truth needed to provide quantitative information on physical, chemical and biological constituents. Such information may enable quantitative estimates between data points.

2. Traditional Approaches

Morphological features are those which can be directly measured from the resulting data. The location, spatial distribution, area, length and form of shoreline, length, breadth, mean breadth, and occurrence of emergent vegetation are examples. Additional model predictions using remotely sensed data as inputs include such features as average and maximum depth, water quality, volume, occurrence of submergent vegetation and other biotic communities, and characteristics of bottom sediments. From these measurements, the various disciplines make specific inferences and management uses of the information.

Certain of the measurements on surface features are best accomplished using specific spectral regions which may not have applications in certain other of the measurements. Therefore, the multispectral system is required to satisfy all uses. Perception of the length and form of shoreline can best be accomplished in landscapes where the shore is vegetated using reflective infrared spectral variations; whereas, if the interface is between water and dark-colored moist soils, the visible spectral region can provide optimal spectral contrast. Therefore, for applications over large geographical heterogeneous regions, a multiband approach as was used in the national dam inspection may be required to effectively apply the remote-sensing procedures. Depth penetration and resulting reflectance anomalies from other than the surface vary with spectral region. Therefore, observations in the shorter visible wavelengths where considerable depth penetration occurs are required to record anomalies which are not apparent at the water surface.

In summary, specific two-dimensional surface features can be measured using reflectance anomalies which define the physical characters of lakes and reservoir. Certain observations in the third dimension, below the waters surface, can be predicted with the remote reflectance measurements.

3. Role of Current Landsat Program

The location and distribution of surface water storage has many important implications. As precipitation falls on the landscape, the major factors in the runoff equations include infiltration into the soil, and collection in basins. Therefore, the lakes serve in a storage capacity to reduce the stream runoff and thereby reduce flood potential and to retain the water in the region for recreation, groundwater recharge, etc.

The large-scale water usage of groundwater has resulted in considerable lowering of the water tables with diminished groundwater reserves in many regions of the country. The Texas High Plains has been an area where considerable irrigation development has occurred and the projected groundwater supplies in the next 50 years in the Ogallala Formation will be only 1/3 of what is available to date. The potential exists to artifically recharge the Ogallala from these shallow lakes. A project was initiated to evaluate the feasibility of developing this potential. Therefore, a data requirement to evaluate the numbers, areas, volumes, and spatial and temporal distribution was realized. Application of aircraft-level information would have been cost prohibitive; therefore, Landsat data were evaluated. The resolution limitation of the data was apparent since the largest proportion of groundwater recharge from a playa lake was in the region where coarse-textured soils existed and the lakes were small. Even with the partial pixel approach applied in a stagnant ice region of North Dakota, only 14 to 18.5 percent of the total ponds and lakes were recorded because of the large numbers of small ponds which were not detected.

Studies in the Northern Great Plains on assessing the volume of stored water in prairie pothole lakes have found that lake areas could be used to account for up to 89% of the variation in lake water volume in the shallow prairie lakes. Therefore, an assessment of stored water volume with time is feasible using remote observations of area. As the trophic status of these prairie lakes is primarily dependent on the depths, the ability to assess the potential of eutrophication is at hand. In addition, this volume is used in water runoff models as the surface water storage input. The ability to use the repetitive coverage characteristics is especially required for these small lakes which are very dynamic.

A study of the prairie pothole lakes in South Dakota using visual interpretation which employs the additional advantage of interpreting photographic textural and pattern properties found that recognition of non-vegetated lakes 1.5 hectares (3.7 acres) and larger could be accomplished at 100% accuracy. Landsat imagery at scales as large as 1:62,500 was used for interpretation. For lakes containing emergent vegetation, areas larger than 3.5 hectares (8.6 acres) could be detected with 90%

or greater accuracy. These photointerpretive methods provided, in general, similar results as the computer processing of digital data.

The various water-resources agencies have the need for total-area inventories but in the Great Plains Region, the existing Landsat capabilities are not suitable for the inventory purposes.

4. Impact of Landsat Follow-on

a. Spectral Regions. The addition of the thermal channel will provide resource planners and managers a complete new tool. Water temperatures as measured by emitted radiation observations will be more reliable than temperatures of most other landscape surfaces because only small variations in emissivity of water occur. The rates of most biological processes are regulated by temperature. Many patterns of water movement are not detected using reflected radiation if suspended particulate matter is not present and does not indicate the water flow. However, many of these flows can be located through temperature anomalies. Where lakes and reservoirs are hydrologically connected with sources of water such as aquifers, the influx of water into the lake which is of different temperature serves to indicate this hydrologic connection. These temperature surveys using ground methods are tedious and time consuming. In addition, chains of lakes over large regions can be evaluated with the same manpower as the traditional evaluation of a single lake with the synoptic coverage of satellite imaging systems. Discharges of thermal pollutants into lake waters can be evaluated and monitored on a repetitive basis. Another specific advantage of the thermal monitoring is the ability for "night vision". The requirement for information during very dynamic times, such as floods, is ongoing both at night and during daylight hours. Many of these observations are of real value but have not been implemented into operational systems because of the present void in data collection capabilities at space altitudes

The proposed spectral bands with shorter wave length intervals should be more specific for discrimination of substances suspended in water. Presently, suspended particulate matter can be detected, however, there is little prediction capability as to its composition. The 0.45→0.52μm spectral region because of its penetration potential will provide an advantage for monitoring lakes and reservoirs. The maximum penetration of electromagnetic radiation into pure water is included in this

region; whereas, the MSS 4 band approached but did not include the peak. Sensitivity to depth variations should also be improved due to the higher incoming radiance associated with the higher sun angles at the time of data acquisition. Bathymetric mapping has been effectively demonstrated in clear waters using the existing sensor capability and this improved capability will be of importance.

b. Resolution Properties. The instantaneous field of view (IFOV) of the Landsat follow-on at ≃30m will perhaps be of the greatest advantage for use in lake and reservoir operations. The existing system provides reliable information for recognition and quantitative measurements for large lakes but is limited for small lakes. The IFOV of the present Landsat system in terms of ground coverage is approximately 0.45 hectares (1.1 acres). The minimum possible dimensions which should always be detectable are twice the directional ground coverage or would correspond to the area covered by four pixels (≃1.8 hectares or 414 acres). The Landsat follow-on IFOV in terms of ground coverage is ≃0.09 hectares (0.22 acres). Therefore, the minimum detectable area would be 0.36 hectares (0.88 acres). Similar arguments for recognizing coves in reservoirs and stream widths would produce recognition of features which were at least ≃156 m wide in track (≃116 m cross track but variable with latitude) for the existing Landsat capability and 60 m wide for the proposed Landsat follow-on. These results apply primarily to digital analyses methods. The analyses program developed for the national inspection of dams was consistent with these expectations and using Landsat data could detect and map water bodies 4 hectares in size and larger with 90% accuracy with a false detection frequency at 10% or less.

The measurement of lake areas will be greatly improved by the increased resolution of Landsat follow-on. For applications in many geographical regions, an accurate area measurement is required in contrast to only lake recognition. If pixels which have a signal of only water are included in the analysis, the areas will always be underestimated. Development of a partial pixel approach has been used to include certain of the border pixels. These approaches have resulted in errors of area measurement of ±8% at 5 hectares in size using Landsat 1 and 2 data. Using photointerpretive techniques for 1:62,500

photographic prints of Landsat data, the errors at the 95% confidence interval were ±26.2% for a 5 hectare lake and ±2.1% for a 200 hectare lake.

Increased resolution is required before operational surveys can be reliably conducted. The small lakes because of their numbers and physical characteristics in many regions are of importance. The Landsat follow-on will provide this required spatial resolution.

Lake bathymetric mapping in any but clear waters even in the better spectral window will probably not supply these maps except for near-shore areas. However, for the location of sedimentation patterns, these near-shore regions are of greatest importance. In addition, the improved spatial resolution will allow the updating of shoreline contours as the guage of the reservoir fluctuates.

The evaluation of shoreline changes including temperature variations in the shoal areas is required to assess the biotic communities and productivity. The existing Landsat system does not possess the resolution capabilities for these assessments. The shallow portion of reservoirs along their margins is the dynamic portion which requires these multitemporal observations but also the higher resolution data.

5. Comments on User Acceptance

As with any developing tool, a considerable time lag exists between the development of the technology and its actual use and implementation. These time lags especially occur with local users in contrast to the large, well-structured users. The Army Corps of Engineers use of Landsat data for the national dam inspection program is, perhaps, the best illustration of a large-effort, coordinated use of the technology. The local water development board of water resources agency will, in general, considerably lag behind in time for the operational use. These agencies may use traditional aerial photography at great expense for resource assessments which could be easily and less expensively conducted using space-acquired data. Many reasons for this may exist. The education in uses and effective procedures may be the most crucial deficiency. The complications involved in maintaining the technological pace of the space program and its investigation products are too demanding for small organizations. This definition of small

organizations may even traverse into state governmental agencies. The illustrative uses to the public generally also involve very complex data analyses systems which are not generally available and which may, for certain applications, be cost prohibitive for the smaller agency.

When these users have available the normal interpretive products provided with the existing Landsat program, they are at scales and resolutions uncommon to the interpreter. The patterns easily recognized on the traditional aerial photography of high resolution may now be textural variations or tonal variations or may be non-existent on the satellite imagery. The synoptic view, multispectral data, repetitive coverage, and other desirable characteristics may be overlooked. Therefore, an increase in resolution of the satellite system as proposed in the Landsat follow-on will definitely increase the user acceptance in their normal operational programs.

6. Summary

The improved spectral and spatial resolution and introduction of new spectral capabilities should provide:

(1) User acceptance of data products by local groups, due to the presence of familiar interpretable features resulting from the greater resolution.

(2) The shift from the required computer processing for large scale mapping to photo interpretation techniques allowing use of data by agencies with limited finances and equipment.

(3) Improved bathymetric mapping.

(4) Location of flow patterns which are only displayed by temperature anomalies.

(5) Improve morphometric measurements to provide reliable data for volume prediction models.

(6) Improved classification of trophic status.

(7) Ability to map shoreline variations with gauge at 30 m horizontal frequencies.

(8) Improved recognition of vegetation occurrence and distribution.

(9) Recognition and mapping of distribution of small water bodies characteristic to many landscapes.

F. WATER QUALITY IN LAKES AND RESERVOIRS

1. Background

Over the millenia, man has come to recognize the benefits to be derived from the exploitation of inland lakes. The intrinsic properties of lakes make them a natural resource whose importance is greater than is suggested by their areal extent. Lakes are used as sources of municipal water, irrigation water, and as cooling water for thermal-electric plants and industrial plants. They serve as transportation routes and as focal points for many types of recreational activity. Their animal populations are harvested for food and clothing. Many lakes, particularly those in pristine condition, are valued for their aesthetic qualities and attract property developers.

Man's strategies for using the earth's lacustrine resources have usually been predicated on immediate short-term economic gains with little consideration of the long range environmental ramifications. It is becoming increasingly apparent that man has adversely affected many lakes, particularly those located in countries with large population densities and/or which are technologically advanced. Lakes serve as convenient locations for dumping the organic and inorganic wastes of society. They function as catch basins to receive runoff-borne nutrients, pesticides, clays and silts which are the by-products of our agricultural, forestry, and earth-moving activities. Lakes are sometimes viewed as impediments to progress and drained to create additional crop lands or filled to provide building sites.

Lakes are by their very nature dynamic and normally passed through a series of successional stages which ultimately lead to their extinction. They are currently exposed to the pressures of modern technology and a burgeoning world population, the net result of which is to effectively shorten their tenure as landscape features.

The effective management of the world's resources requires, among other things, a knowledge of their location, quantity, and quality. In the case of lakes, it is of value to resource managers, planners, and governmental units to know the water bodies': geographic locations, distribution patterns, surface areas, morphometric and hydrologic characteristics, flora and fauna, and trophic condition. Any attempt to make an inventory of a large number of lakes using conventional field sampling

techniques would be very expensive and time consuming. Indeed, much of the data would be dated before the survey was completed.

In the United States, for example, there are an estimated 80,000 - 100,000 lakes. New lakes are constantly being formed, others are being drained or have succumbed to the effects of eutrophication and siltation. Some are ephemeral, containing water for only a few days or weeks; others will occasionally suffer a complete loss of water during extended periods of drought. Many of the estimates of the total number of lakes within a large region or political unit are made on the basis of figures generated from topographic sheets, which in many cases are outdated. More than one compiler of lake statistics has gone out into the field to verify the presence of a lake only to find that it has been replaced by a park, complete with tables, benches, mature trees, and grass. The point is that the standard techniques used to survey our lake resources are inadequate when large numbers of lakes are involved. It is difficult for resource managers to maintain current registers of the number of lakes under their jurisdiction, much less current data on surface area and trophic condition.

The past decade has witnessed an increased awareness and concern among many citizens for the quality of the environments. In many cases, governments have reacted positively to the concerns of their citizens by passing legislation to protect the environment. The environmental legislation often requires that surveys be conducted and inventories be maintained of the condition of the environment. Such legislation, while serving a desirable function, places an additional burden on both the governmental and private sectors of the economy. In many cases the particular organization which is to respond to the legislation does not have the necessary manpower and/or funding to meet the directives using conventional survey and monitoring techniques.

For example, the 92nd Congress of the United States passed what is commonly referred to as Public Law 92-500 and entitled, "Federal Water Polution Control Act Amendments of 1972". Several sections of the amendment act stipulate that the states are required to conduct an inventory of their waters and develop a classification. Under PL 92-500 the states are required to take an active role in evaluating and reporting on the qualities of their waters. Such a task can be very formidable, especially at a time when many governmental bodies are suffering from the effects of

manpower reductions, budget cuts, and inflation. The need exists for techniques or methodologies which can provide the necessary information rapidly, repetitively, and at low cost relative to conventional methods. It would appear that satellite-borne remote sensors might well fill the need.

2. Traditional Approaches

The number of lake parameters included in a lake survey along with their spatial and temporal sampling frequencies is a function of many factors including: the specific objectives of the study, the number of lakes under scrutiny, and budgetary and manpower considerations. Parameters determined during a typical lake survey might include:

surface area	dissolved oxygen
length of shoreline	chlorophyll a
maximum depth	total phosphorous
mean depth	dissolved phosphorous
retention time	total nitrogen
water temperature	inorganic nitrogen
secchi disc depth	total organic nitrogen
suspended solids	heavy metals
water color	flora (species, biomass)
lake color	fauna (species, biomass)
conductivity	turbidity

The above listing is by no means complete and merely serves as an example. The temporal aspects of the sampling may range from less than once a year to daily. The number of sampling stations will typically range from one to several. As a rule, only lakes possessing unique qualities or those of very special economic importance are subjected to an intense sampling program. Indeed, most of the lakes in the United States are largely ignored because of the magnitude of the task. Not only are the conventional approaches used to sample lakes very expensive and time-consuming, but the data are "dated" in programs where large numbers of lakes are sampled.

3. Role of Current Landsat Program

The successful launching of Landsat 1 afforded scientists and other individuals concerned with lakes the opportunity to investigate the feasibility of employing a new tool with which to survey and monitor

lakes. The deployment of the satellite was viewed with interest because it promised the advantages of repetitive coverage (18-day cycle), offered a synoptic view of the earth's surface, recorded electromagnetic radiation in several spectral bands, had relatively high spatial resolution (approximately 80 meters), and was sun-synchronous (9:30 a.m. equatorial crossover).

The visual examination of many Landsat 1 multispectral scanner scenes from different parts of the United States has reinforced the idea that the system is capable of recording lake-related phenomena which might correlate with parameters of interest to lake scientists and ultimately to resource managers. Figure II-1 is a reproduction of an EROS Data Center photograph of Landsat 1 MSS Scene 1017-16093 recorded over Southeastern Wisconsin and Northeastern Illinois on August 9, 1972. The photograph depicts the Band 7 (Infrared-two: IR2; 800 to 1,100 nanometer) energy return over an area of some 34,000 square kilometers. Water bodies, including the larger streams, stand out boldly against the lighter tones of the land features. While gray tone differences are not evident between the lakes nor are tonal patterns visible on any of the lakes, the IR2 band is an excellent band for the location and demarcation of water bodies.

Figure II-2 is the same scene recorded in red light (Band 4; 600 - 700 nanometers). Marked gray tone differences are apparent between the lakes. Lakes commonly recognized as eutrophic (e.g., Lake Como) tend to be light in tone and meld in with the land features. Lakes with relatively good water quality (e.g., Lake Geneva) are characterized by darker tones. While not shown here, differences between lakes are also evident in photographs developed from the two remaining MSS bands (Band 4: green, Band 6: Infrared-on).

Many individuals and organizations have been active in determining the feasibility of using Landsat MSS data to survey and monitor the lacustrine resource. Some investigations have been limited by circumstances to working with EROS-supplied imagery; others have been able to take advantage of the Landsat digital data contained on computer-compatible tapes. Information of value to lake scientists and resource managers has been derived from both the MSS imagery and the CCTs. A brief discussion of some pertinent investigations follows.

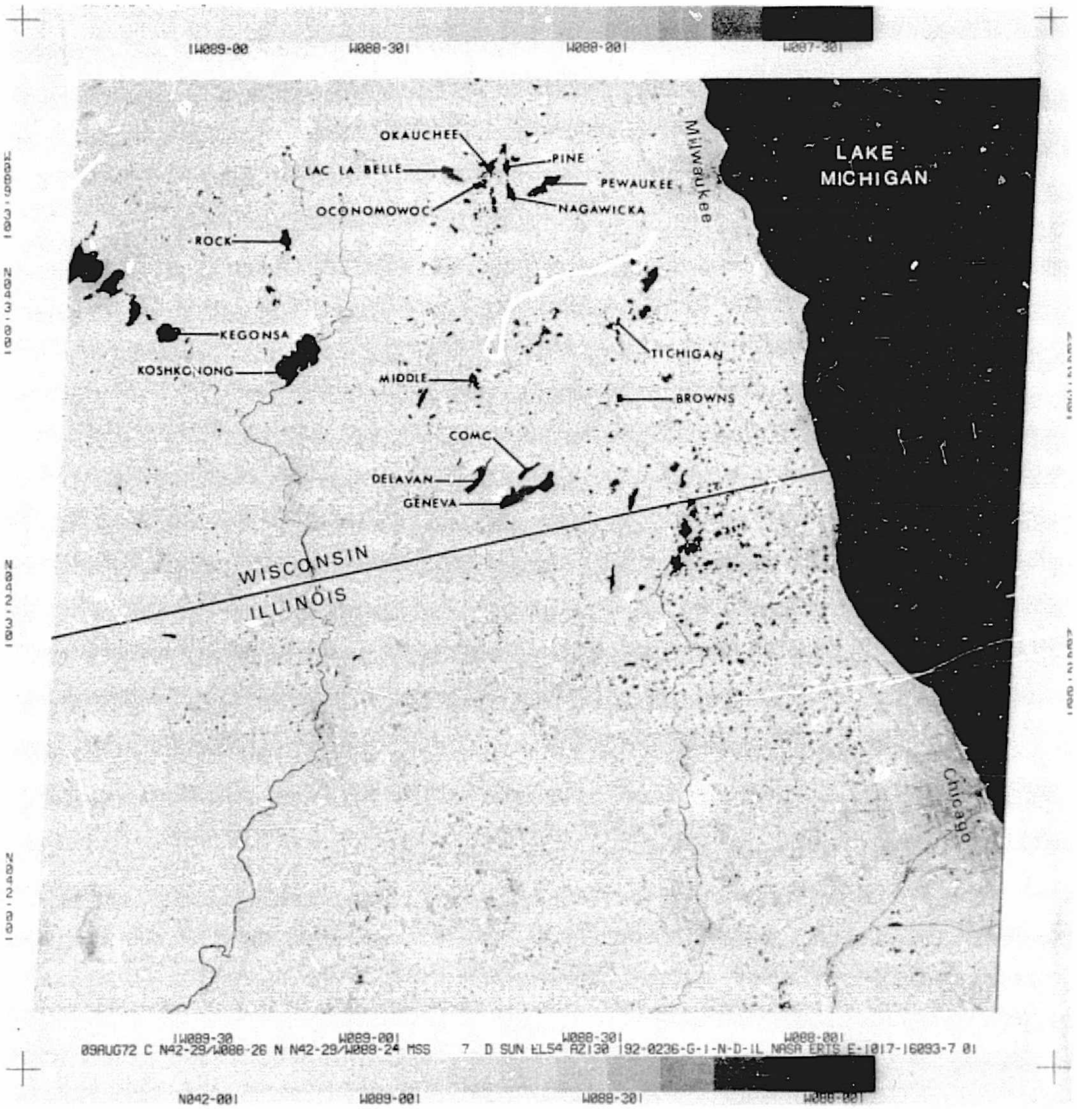


FIGURE II-1. Reproduction of an EROS Data Center IR2 print of scene 1017-16093. The water bodies stand out boldly against the lighter-toned land features.

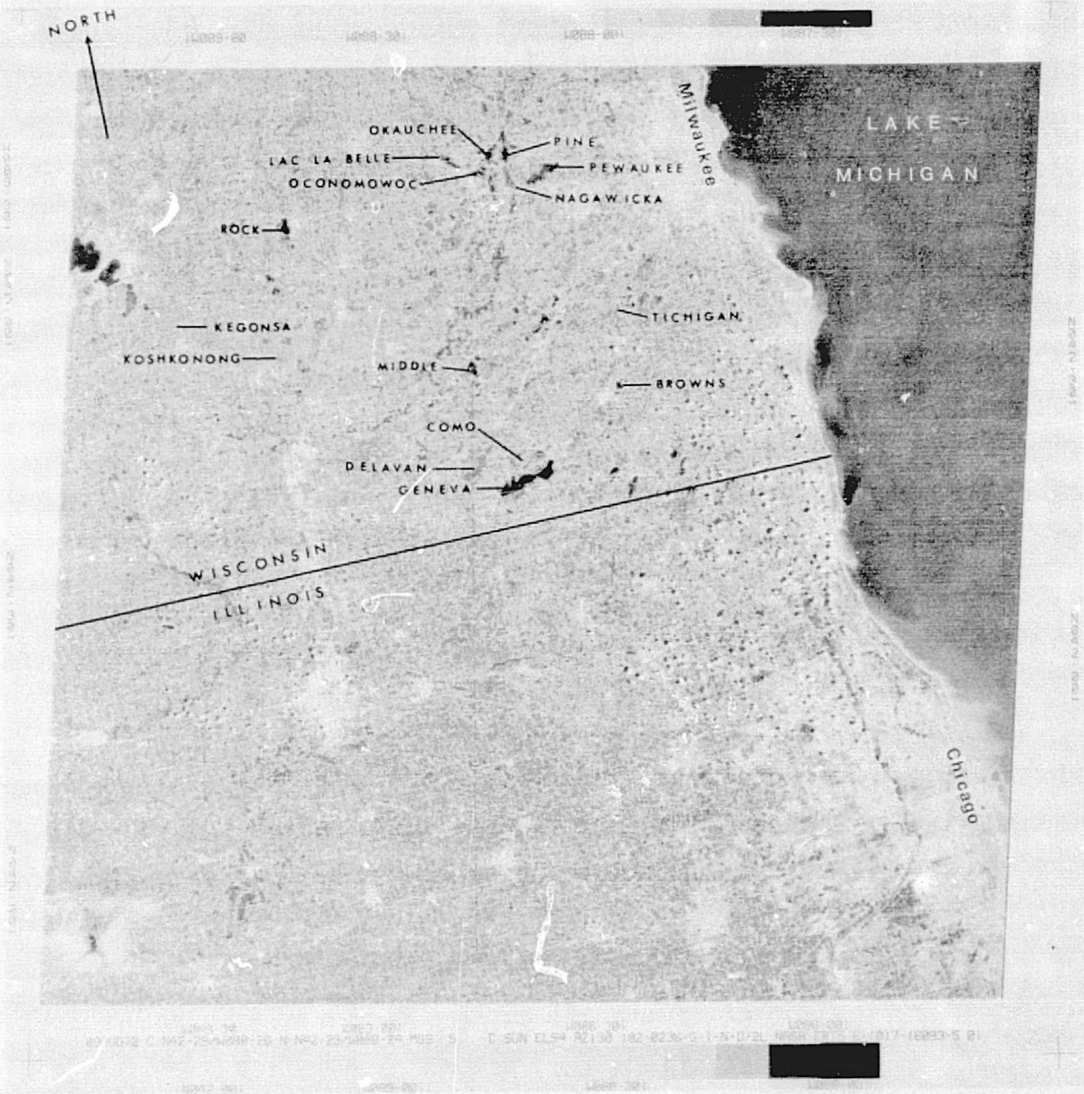


FIGURE II-2. Reproduction of an EROS red (MSS Band 5) print of scene 1017-16093. Variations in gray tone are readily apparent between the lakes and suggest differences in water quality. Lake Geneva, characterized by relatively high water quality is dark in tone compared with, for example, eutrophic Lake Koshkonong

Decreases in water transparency are generally related to increases in lake trophic state and/or increases in suspended inorganic materials. The Secchi disc is still widely employed in lake monitoring and survey programs to give an estimate of water transparency or its inverse, turbidity. Many investigators have demonstrated that it is possible to estimate Secchi disc transparency using the Landsat MSS data (e.g., Yarger and McCauley, 1975; Moore and Haertel, 1975; Boland, 1976). The Secchi disc transparency estimates derived from MSS data are of practical value. Rogers, Reed, and Smith (1975) have shown the feasibility of mapping Secchi depth (turbidity) in Lake Huron.

Some Landsat studies have focused on the estimation of suspended sediment loads in water. Lakes normally contain sediments of both organic and inorganic origin. The waters of eutrophic lakes tend to have relatively large amounts of organic suspenoids. Other lakes and reservoirs have suspended sediments consisting largely of silt and clay particles. In each, water quality declines as the concentration of solids increases. Yarger and McCauley (1975), for example, have shown that Landsat MSS data can be used to estimate suspended sediments in Kansas reservoirs with a 67% confidence interval of accuracy of 12 parts per million (ppm) over the range of 0-80 ppm and 35 ppm over the range 0-900 ppm.

It is apparent from the findings of many Landsat investigators that the detection of large turbidity plumes and turbidity related patterns in lakes is easily accomplished using MSS imagery (e.g., Pluhowski, 1973, Lind and Henson, 1973). Inferences about lake circulation can be drawn from the patterns. Bukata, et al. (1975) have used Landsat data to study water transport phenomena in Lake Erie. The ability of Landsat to detect circulation-related patterns can be of great value in formulating lake sampling strategies (e.g., siting of sampling stations).

The detection of algal blooms is a straightforward procedure with Landsat MSS data. Strong (1973) has vividly demonstrated the presence of algal blooms in Utah Lake and Lake Erie, Bukata, et al. (1974) have shown that MSS data are directly correlated to surface biomass concentrations in mg/m^3. Hidalgo, et al. (1973) have detected large mats of duckweed (lemnaceae) on Lake Pontchartrain and its surrounding swamps and bayous. In lakes where inorganic sediments have not masked the

TABLE II-7
APPLICATION ASSESSMENT TABLE

Application:

Lakes and Reservoirs

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Lakes and Reservoirs (Including Quality of Water)		
Water Storage Volumes.	1. a. Area	+3	Spatial.
	b. Gauge	0	(probably restricted to DCS).
	c. Bathymetry	-2	Spectral.
Physical Storage Degradation.	2. a. Shoreline Change	+1	Spatial.
	b. Turbidity	+1	Spectral, Spatial, Quantization.
	c. Sedimentation.	-1	Spectral, Spatial, Quantization, Frequency.
	d. Macrophytes.	+1	Spectral, Spatial.
	e. Circulation.	+2	Spatial, Spectral, Frequency, Quantization.
	f. Algal blooms.	+2	Spatial, Spectral, Frequency, Quantization.
Trophic Classification.	3. a. Secchi-Transparency.	+1	Spatial, Spectral, Frequency, Quantization.
	b. Suspended solids.	+1	Spatial, Spectral, Frequency, Quantization.
	c. Nutrient Levels.	-3	No new benefits.
	d. Chlorophyll 'a'	+1	Spatial, Spectral, Frequency, Quantization.
	e. Macrophytes.	+2	Spatial.
	f. Algal blooms.	+2	Spatial, Spectral, Frequency, Quantization.

presence of chlorophyll, it has been possible to show a good correlation between MSS data and chlorophyll a.

The feasibility of classifying lakes according to trophic state has been demonstrated by several investigators (e.g., Fisher and Scarpace 1975, Boland and Blackwell 1975).

A survey of the literature indicates that the Landsat observatory and its MSS can play a practical role in lake monitoring and survey programs. It supplies information formerly unavailable to researchers and planners. The system does, however, suffer from several deficiencies which, in turn, have a detrimental impact in lake studies.

4. Deficiencies in Current Landsat Program

Lakes are dynamic and can show significant changes within a matter of days or even hours. It is very important in most lake-oriented studies that the sensing system provide good data and on a frequent basis. Efforts to employ Landsat data in lake programs have had to cope with several problems.

The 18-day coverage cycle would be adequate for lake work if, indeed, atmospheric conditions permitted an unimpeded view of the earth's surface. However, excessive cloud cover greatly reduces the chances of receiving usable imagery. The magnitude of the problem is increased by occasions when the MSS data received are of poor quality. Instead of receiving approximately 20 scenes a year of a specific point of interest (ignoring side overlap), the investigator often has to settle for less than 50% of that number, many of which were not recorded at the best time for observing, for example, the manifestations of eutrophication. When a study area covers a large geographic area requiring several Landsat frames or scenes, the chances of working with a complete temporal-spatial MSS data set are nearly zero.

The Landsat MSS bands are optimized for land studies. The energy return from water is very low and although the four bands contain information which is related to water phenomena, it is in a very small range of digital number levels.

While the 80 meter MSS resolution is adequate for most work in very large lakes, it is a handicap in smaller lakes (e.g., less than 500 hectares) and in the detection and mapping of aquatic macrophytes and small turbidity plumes. The resolution also results in problems relating to the location of lake sampling sites.

The time between satellite flyover and receipt of the MSS data by the user is another problem area. In many cases, data processors have to wait for many weeks and even several months for the CCTs. The long turn-around time hinders lake researchers and discourages resource managers.

5. Impact of Landsat follow-on

An examination of the Landsat follow-on parameters in light of knowledge acquired through Landsat 1 and Landsat 2 lake-related investigations suggests that most of the specifications will increase the utility of the system in lake studies. The following remarks are addressed to the thematic mapper (TM) and the overall system.

The improved spatial resolution of the TM will permit the more accurate mapping of turbidity plumes, demarcation of shorelines, plotting of currents, and delineation of large beds of aquatic macrophytes. It is anticipated the smaller pixel size will result in the inclusion of small lakes into survey programs.

The band selection is an improvement and should permit better estimates of parameters such as chlorophyll a. The addition of the blue band may add a new dimension to the remote sensing of water. Work by Piech, et al., (1975) has shown the value the blue in water-related studies. However, it is likely atmospheric effects will be severe and that corrective measures will have to be taken. The thermal band (10,400 - 12,500 nanometers) will be of value in the determination of lake surface temperatures; however, it will be less effective in monitoring lake thermal plumes because of its 120 meter resolution.

The increase of quantization levels from 127 to 256 may be of value if this means that the dynamic range of the sensor has actually been increased.

Benefits will be more readily derived from the Landsat follow-on than from Landsat 1 and 2 if NASA reduces significantly the time lapsing between data acquisition by the satellite and receipt by the users.

The insertion of two satellites so as to provide repetitive coverage on a 9-day basis is an improvement over the 18-day single satellite concept. However, as is evident from the experiences derived from the tandem Landsat 1, Landsat 2 coverage, temporal coverage of the lacustrine resource will still be fragmentary. The fragmentary coverage

aspect of the proposed system is a major problem. If the TM performs according to specifications, it will be an improvement over the MSS. The technological improvements will not be fully evident unless the subjects under observation are remotely sensed at more frequent intervals.

Still another problem is that of sun glint. If the projected equatorial crossover time of 11:00 a.m. is used, sun glint is likely to make the satellite of little value in water quality - related work. Water quality depends highly upon volume reflectance which in this case will be masked by the specular reflection (sun glint).

G. LAKE ICE

1. Background

Until recent years, navigation in the Great Lakes-St. Lawrence Seaway System was suspended every winter because of adverse effects of weather and ice. As a result, commerce and industry served by this great waterway system had to stockpile materials for the winter or move cargoes during this period by more expensive and energy-intensive modes of transportation. For many years and particularly since the opening of the Seaway and the development of Taconite, which doesn't freeze into a solid mass, commercial shipping interests have sought an extension to the navigation season in order to make maximum use of this vast inland waterway. In recognition of the potential benefits of an extended navigation system, Congress in the 1965 River and Harbor Act (Public Law 89-298) authorized the U.S. Army Corps of Engineers to investigate the feasibility of extending the navigation season in the Great Lakes-St. Lawrence Seaway System.

After a review of world-wide experience in ice navigation and ice management techniques, it was concluded that present technology was sufficiently advanced to make winter navigation in the Great Lakes-St. Lawrence Seaway System physically possible. Estimates of prospective traffic and benefits clearly indicated sufficient economic potential to warrant futher investigation and development.

The River and Harbor Act of 1970 (Public Law 91-611) under Section 107 authorized a Winter Navigation Program consisting of three related parts: Survey Study, Demonstration Program and Insurance Study.

The Demonstration Program was to be reported to Congress not Later than 30 July 1974. The Water Resources Development Act of 1974 amended this date to 31 December 1976. The Secretary of Army, acting through the Chief of Engineers in cooperation with a number of interested Federal agencies, was authorized to investigate the practicability of extending the navigation season on the Great Lakes-St. Lawrence Seaway System. The Demonstration Program was established to include, but not be limited to, ship voyages extending beyond the normal navigation season; observation and surveillance of ice conditions and ice forces; environmental and ecological investigations; collection of technical data related to improve vessel design, ice control facilities and aids to navigation; physical model studies; and coordination of the collection and dissemination of information to shippers on weather and ice conditions.

In 1964 the International Joint Commission granted temporary authority to the Hydro-Electric Power Commission of Ontario and the Power Authority of the State of New York, to install an ice boom during the winter season near the entrance-way to the Niagara River from Lake Erie. The purpose of this boom is to accelerate the formation of a stable ice cover in the eastern end of Lake Erie, reduce movement in the ice cover while it is being formed, and help to stabilize the downstream edge of the ice cover so that erosion and break off of ice is reduced. The boom provides added resistance to breakage of the natural arch under storm conditions. The desired effects of the ice boom are distinctly advantageous towards achieving optimal hydro-electric power generation on the Niagra River. Additionally, shore line property damage due to massive ice runs has undoubtedly been reduced along the entire Niagara River.

2. Traditional Approaches

The National Oceanic and Atmospheric Administration with its component the Great Lakes Environmental Research Laboratory, is the lead agency and serves as chairman of the Ice Information Work Group. Program activities encompassed the development of service products necessary for winter navigation, rapid dissemination of these products to users, collection of supportive data, and surveillance and monitoring of ice and weather conditions. The Ice Navigation Center at the Ninth Coast Guard District Office in Cleveland served as a focal point for collection

and dissemination of information required to aid shippers during the extended navigation season.

The Ice Navigation Center is staffed and operated jointly by the Coast Guard and the National Weather Service of NOAA. The main mission of the Center is to collect and disseminate ice observations and forecasts for both government agencies and commercial interests participating in the Demonstration Program. Thus far, since navigation in areas below the Welland Canal has been limited, no concerted effort has been made by the Center to maintain complete ice information on a real-time basis.

a. Great Lakes Ice Information Network. Various elements associated with the 1974-1975 and 1975-1976 Ice Information Program are outlined in Figure II-3. A multi-engine, U.S. Coast Guard C-130 aircraft equipped with an all-weather microwave SLAR routinely surveyed selected regions of the Great Lakes.

SLAR has two important characteristics which make it especially suitable for ice mapping over the Great Lakes. Because SLAR uses microwave radiation which readily penetrates heavy cloud cover, high-quality SLAR images may be made even in conditions of total cloud cover. This all-weather capability makes it possible to obtain imagery on a daily basis, if desired, in a region which is covered with clouds much of the time during the winter. Secondly, since SLAR produces its own illumination (radar pulses) and does not depend on reflected solar radiation as do other systems such as cameras or television, SLAR images may be made at any time of the day or night.

The tape recorded information is transmitted to the U.S. Coast Guard Ice Navigation Center in Cleveland, Ohio, over two possible communication networks: (1) a near real-time transmission from the SLAR aircraft to selected shore stations around the Great Lakes by an S-Band microwave downlink and onto the Ice Navigation Center by special dedicated telephone lines or (2) by a continuous real-time transmission from the SLAR aircraft to the SMS/GOES Satellite in geosynchronous orbit by a VHF uplink from the aircraft and a subsequent microwave downlink from the satellite to the Wallops Island, Virginia, Ground Station and onto the Ice Center by special dedicated telephone lines.

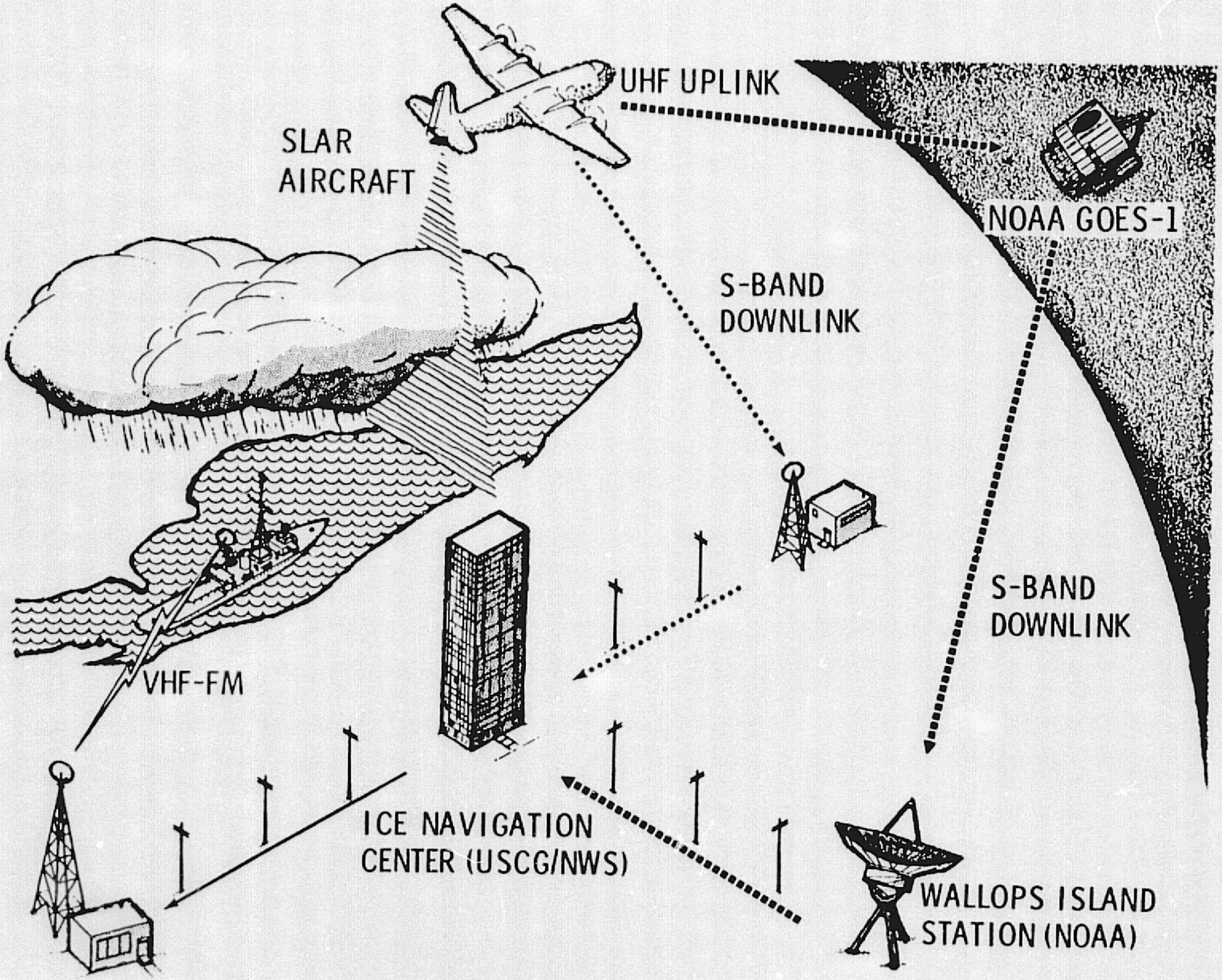


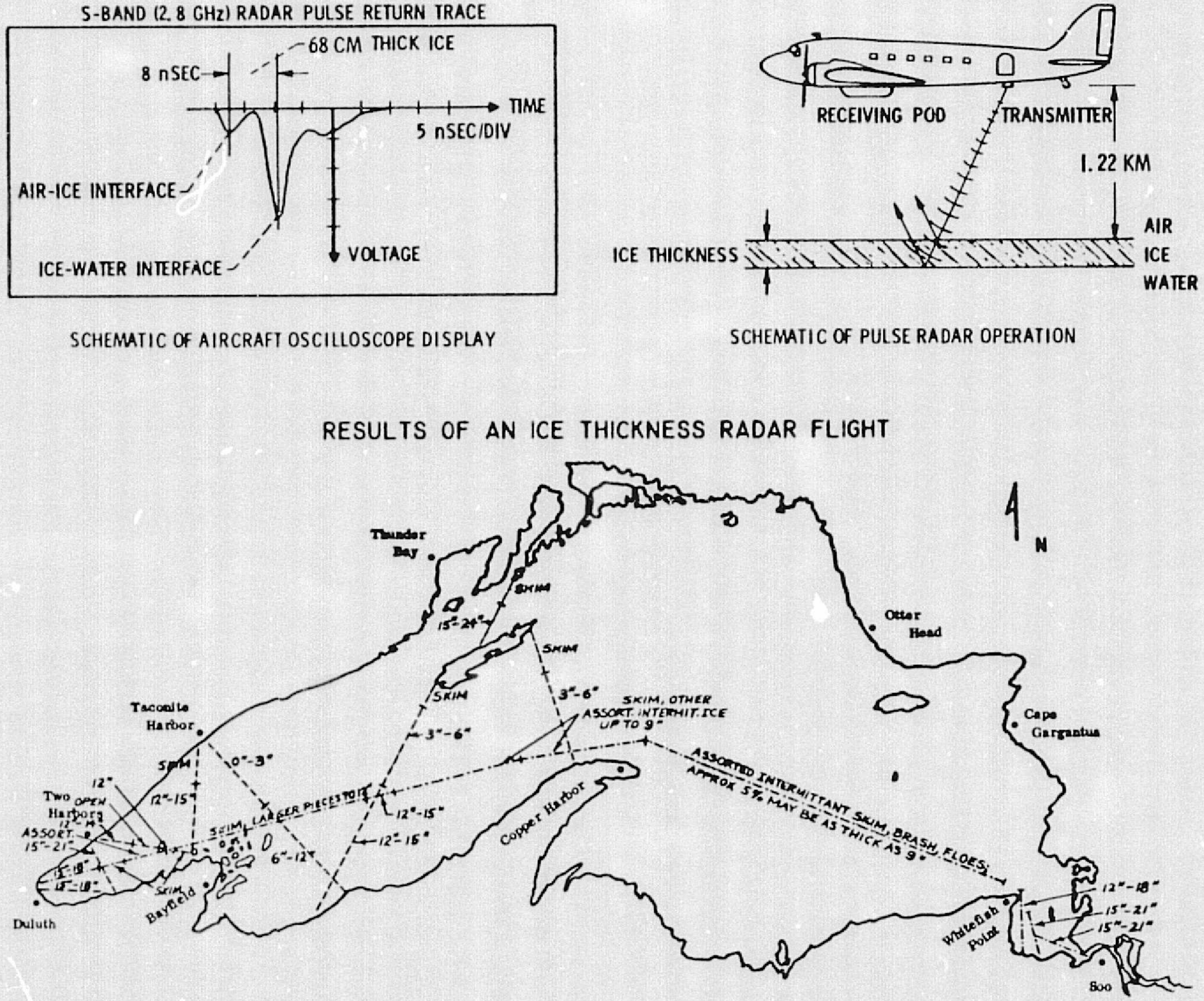
Figure II-3 Schematic of the Great Lakes Microwave Ice Information Program (Project Icewarn).

The subsequent interpretation of the SLAR image will be presented in the form of an ice chart. The ice charts will also contain ice thickness measurements obtained from the NASA Short-Pulse Ice Thickness Radar as well as any additional relevant ice information available to the Ice Center. This combination of a SLAR image and the interpretive ice chart from the various winter shipping areas in the Great Lakes will be transmitted from the Ice Center by a facsimile scanner to the Lorain Electronics Corporation in Lorain, Ohio over a special dedicated telephone network. As soon as a Product is prepared and at other pre-arranged times throughout the day, these Products will be rebroadcast over the Lorain MARAD and Central Radio Marine VHF networks to vessels operating on the Great Lakes equipped with the appropriate facsimile receiver.

In order to facilitate the use of the actual SLAR imagery for vessel navigation, transparent overlays of the Great Lakes Navigation Charts for Lake Superior, Straits of Macknac, Lake Huron, Lake St. Clair and Lake Erie will be provided to each vessel equipped with the ice information facsimile receivers. These transparent overlays will match the scale of the received Facsimile Products (1:762,000). The overlays will allow the ice cover as portrayed in the SLAR image to be seen in relationship to various land features and standard Great Lakes vessel tracks. The accompanying ice chart provides a valuable and necessary complement to the SLAR image not only by delineating the boundaries of the various ice areas but also by incorporating additional information such as ice thickness measurements obtained from NASA short pulse radar (see Figure II-4). The SLAR Image/Ice Chart Products and Wind-Temperature Forecast Charts are transmitted at regularly scheduled times throughout the day. The starting times for these broadcasts are shown in the table below. The SLAR will also be transmitted as soon as they are drawn up in the Ice Center.

SLAR Image/Ice Chart Products	1:00 a.m. 8:00 a.m. 10:00 a.m. - 4:00 p.m. as each new chart becomes available 7:00 p.m.

ICE THICKNESS RADAR



SCHEMATIC OF AIRCRAFT OSCILLOSCOPE DISPLAY

SCHEMATIC OF PULSE RADAR OPERATION

RESULTS OF AN ICE THICKNESS RADAR FLIGHT

LAKE SUPERIOR SUMMARY ICE CHART
DATE: 28 MAR 74 - - - - - - - - -
29 MAR 74 —- —- —- —

WINTER NAVIGATION SEASON PROGRAM
COAST GUARD / NWS / NASA / ARMY

Figure II-4 Results from a typical NASA S-Band (2.8 GHz) Short Pulse Ice Thickness flight.

Wind Temperature Forecast Chart	2:45 p.m. 8:45 p.m.

During the 1974-1975 winter shipping season, short pulse ice thickness radar flights were conducted on a regular basis to provide a comprehensive thickness profile of the various ice types and ice areas. Flights on the order of once a week should provide adequate coverage except during periods of rapidly fluctuating ice conditions. At these times, more frequent flights are anticipated especially in critical navigation areas of the Great Lakes such as the Straits and Whitefish Bay.

Charts such as shown in Figure II-5 depicting the ice thickness profile along the various flight paths is prepared in flight and transmitted directly from the aircraft by facsimile through the MARAD VHF Network to the Ice Center at the completion of the various flight segments. At the Ice Center this thickness information is incorporated into the latest products.

b. Program Funding. Under the River and Harbor Act of 1970, $6.5 million was originally authorized for a three-year demonstration program. The Water Resources Development Act of 1974 increased the amount to $9.5 million and extended the program 2 1/2 years. The Winter Navigation Board was allotted a total of $8.8 million for the five years of the program. As presently authorized, this leaves a balance of $620,000 for the Transition Quarter and FY-77 activities. These funds were distributed to the work groups for the various programs as shown in the table below.

DEMONSTRATION PROGRAM FUNDING

Program Element	Total FY72-FY76
Ice Information	$1,357,000
Ice Navigation	1,528,000
Ice Engineering	360,000
Ice Control	1,455,000
Ice Management	2,329,000
Economic Evaluation	58,000

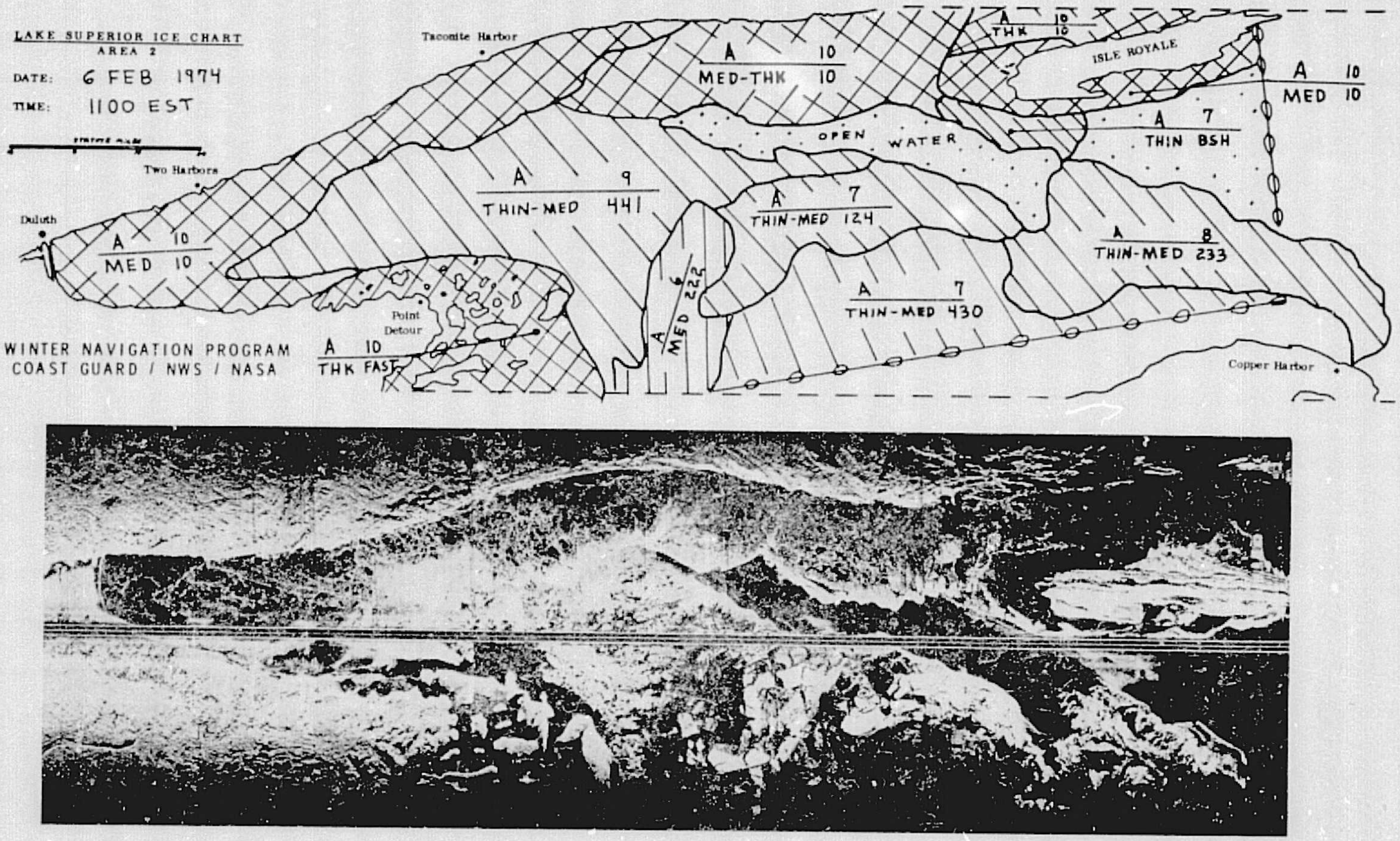


FIGURE II-5 SLAR IMAGE/ICE CHART PRODUCT FOR THE WESTERN PART OF LAKE SUPERIOR ON FEBRUARY 6, 1974

Program Element	Total FY72-FY76
Subtotal	$7,698,000
Environmental Evaluation	669,000
Program Management	1,019,000
Public Affairs Subcommittee	105,000
Total	$8,880,000

c. Cost. The costs associated with the interim selected plan are displayed in the table below. Costs are based on December 1975 prices.

UPPER FOUR GREAT LAKES
SELECTED PLAN
TOTAL ANNUAL COSTS OF NAVIGATION SEASON EXTENSION TO 31 JANUARY
AT 6 1/8% INTEREST RATE

CAPITAL REPLACEMENT ITEMS	FIRST COSTS
Ice Reconnaissance Aircraft and Support Equipment (A)	$ 8,516,800

OPERATIONAL ITEMS	ANNUAL OPERATIONS & MAINTENANCE
Ice Breaking Assistance (A)	$1,637,000
Ice Navigation Center Operations (A)	35,360
Ice Reconnaissance (A)	176,000
Navigation Aids Deployment (A)	9,790
Ice & Water Data Collection (C_1)	46,000
Ice & Weather Forecast Operations (C_2)	72,000
Ice Jam Monitoring in St. Clair and St. Marys Rivers (B)	6,250
Port Huron Ice Bridge Monitoring (B)	750

(A) U.S. Coast Guard
(B) U.S. Army Corps of Engineers
(C_1) NOAA - Great Lakes Environmental Research Laboratory
(C_2) NOAA - National Weather Service

Estimates of annual charges were based on an economic life of 50 years and an interest rate of 6 1/8%.

3. Role of Current Landsat Program

Landsat 1 MSS bands 5 and 7 have been used to identify melting snow. Similarly, Landsat 1 MSS images over Lake Erie were examined for melting ice. The ice field in band 5 exhibits a highly reflecting but "lacy" appearance resulting from many thaw holes, a characteristic of "rotten" ice. i.e., deteriorating under warm temperatures. A great

decrease in apparent reflectivity in band 7 as compared to band 5 also indicates melting conditions in agreement with the experimental results of O'Brien and Munis (in press).

Identification of Ice Types. Landsat 1 MSS imagery over Lake Erie has been examined and the following features tentatively identified are: ground ice west of Pt. Aux Pins, Ont.; an icefoot near Marblehead, Ohio and along the east edge of Pt. Pelee, Ont.; a compacted ice edge of the southern edge of the icefield northwest of Cleveland, Ohio; a young ice-snow sheet broken up by wave action east of Pt. Aux Pins; and brash belts oriented almost N-S between Painesville and Astabula, Ohio.

The following ice features have been tentatively identified from the February 17-18 and March 8, 1973, Landsat 1 MSS images of Lake Erie and Lake Ontario (Note that ground truth is not available for verification). Shuga, light and dark nilas, fast ice, icefoot, ice breccia, brash ice fracturing, ridging, rafting, sastrugi, thaw holes, rotten ice, ice floes, dried ice puddles, hummocked ice and leads. These terms are defined in WMO Sea-Ice Nomenclature WMO/OMM/BMO No. 259 TP 145.

The best technique now available for ice study is a combination of Landsat data, the current NOAA operational environmental satellite, and aerial reconnaissance using SLAR and short pulse radar. In this way frequent observations can reveal the rate of response of the water/ice to meteorological conditions. The Landsat data will provide the detailed identification, and the VHRR aboard the NOAA spacecraft can provide the more frequent spatial and temporal coverage required.

For monitoring ice conditions, Landsat 1's 18-day revisit cycle again presents problems as ice formation, movement and breakup may all take place within very short time thus possibly go totally unrecorded by the Landsat 1 sensors.

4. Impact of Landsat follow-on

The Landsat 1 as an ice observation satellite is severely limited in one respect: the revisit period is far too long. The 9-day repeat cycle is a great improvement over the 18-day cycle since the ice conditions change with meteorological conditions. Surface temperature of ice is affected by many factors, e.g., air temperature, water temperature, thermal conductivity of ice, ice thickness, and surface emissivity. In turn, snow cover and wind speed also affect some of these

TABLE II-8
APPLICATION ASSESSMENT TABLE

Application:

Lake Ice Monitoring

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
Areal extent of ice cover.	1. Frequent repeated images of lakes (Great Lakes) (4)	A day coverage will help but more frequent coverage is necessary. -2	
Condition of ice . absolute and relative thickness of ice . ice movements, currents	2. A great decrease in apparent reflectivity in band 7 as compared (4) to band 5 indicates melting conditions.	+2	
Types of ice on lake.	3. "Lacy" appearance of ice.	+2	
Need determination (in near real time) of absolute and relative ice thickness for winter navigation.	4. Ice features on images (directly identified) such as shuga, nilas, fast ice, ice foot, ice breccia, brashice, fracturing, ridging, rafting, sastrugi, thawholes, rotten ice puddles, hummocked ice and leads as defined in WMO Sea-Ice Nomenclature WMO/OMM/BMO No. 259 TP 145.	+2	
	(4) Use of radar and/or other techniques to determine ice thickness.	-3	
	(5) VHRR capability (NOAA).	-3	Available in NOAA environmental sa[illegible]lite.
Ice areal coverage.	Visual spect.	+3	
Thickness.	Thickness.	0	Radar measurements.
Cracks, leads.	High resolution areal information.	+3	
M[illegible]t rate.	Surface temperature albedo.	+3	10.5 - 12.5 μm
Movement.	High resolution areal information.	+3	Side-lap and frequent repeat.
Distribution of ice, leads, thickness, class of ice, temperature.	Pattern recognition, leads, fractured ice, frazil ice, thickness.	May be able to detect some leads and classify some ice types but probably cannot detect thickness.	Problem is need for quick return of data otherwise data is of little value. Problem to determine thickness 18 day cycle is inadequate for shipping operation.

variables. Although Webb (1974, p. 209) has pointed out that thermal data for the ice covered surfaces of the Great Lakes, especially Lake Erie, have not been available previously, these data are now available for possible refinement of the ice dissipation model.

The best technique now available for ice study is a combination of Landsat and current NOAA operational environmental satellite, and aerial reconnaissance using SLAR and Short Pulse radar. In this way frequent observations can reveal the rate of response of the water/ice to meteorological conditions. Landsat can provide the detailed identification, and the VHRR aboard the NOAA spacecraft can provide the more frequent spatial and temporal coverage required, while the aircraft can provide vital details of ice types and thickness. The combination of satellite observational vantage point with other data sources, verified by ground truth, permits detailed analysis of the effect of winds, ice type, depth, currents, temperature, etc. on the formation and migration of lake ice.

The Landsat follow-on data, with increased spectral response and improved spatial resolution, will be used for Lake Ice Monitoring for input into the Navigation Season Extension Program. Landsat follow-on will not eliminate the need for conventional monitoring techniques, but it will, when available, provide a regional assessment of ice conditions, at a much lower cost than conventional methods. A comprehensive lake ice monitoring program must utilize several means of monitoring, data collection, and analysis including airborne SLAR, short pulse radar, NOAA environmental satellite VHRR data, and Landsat data. For extending winter navigation information concerning absolute and relative ice thickness and ice type must be available on a near real time basis. Landsat data will facilitate monitoring and classification of lake ice on a regional scale. When available, Landsat data will reduce the cost of data collection and will provide accurate data over a large area.

No single tool would be of more value to ice forecasters than a quick-look ERTS image of the Great Lakes, especially if it could be available much more frequently than every 18 days. We predict that ultimately ERTS-type data will be used by the Ice Forecast Center in Cleveland, and by operational elements of the U. S. Coast Guard, not only to forecast conditions but to route shipping and to control the activities of their ice breakers and helicopters.

H. SEDIMENT PROBLEMS

1. Background

Suspended sediment is the single most serious pollutant of water bodies. Objectionable levels are created principally by the activities of man. Whenever the vegetation cover is removed or the soil disturbed, invariably, this is reflected in the levels of sediment entrained or suspended in adjacent water bodies.

There are other circumstances, however, that also lead to very high sediment loads in streams and concomitant high sedimentation rates in the water bodies receiving their discharge. In high alpine environments, where vegetation is lacking and heavy snow and ice accumulations together with very active frost action combine to produce accelerated erosion, streams may be heavily laden with silt. At higher latitudes, in heavily glaciated areas, suspended sediment loads are particularly high and sedimentation rates are extremely high.

High sediment loads are particularly troublesome in navigable rivers, inlets, channels and harbors. Enormous labor and expense are involved in removing unwanted sediment and in maintaining navigation and docking facilities. Changes in natural sedimentation regimes have an enormous potential for damaging fisheries and for setting into motion unfavorable long-term changes in the balance of ecological systems that are presently only partly understood and remain as yet unevaluated, in general.

2. Role of Satellite and Aircraft Remote Sensing

The usefulness of aerial and satellite imagery in monitoring sediment distribution and sedimentation processes has been demonstrated in the Straits of Georgia (Tabata, 1972); at South Pass, Mississippi River, (Coleman, et al. 1972) and the Mississippi River delta (Walsh, 1969), at Long Island, New York (Pluhowski, 1972) and at Cook Inlet, Alaska (Barnwell and Zenone, 1969; Gatto, 1972; and Anderson, et al. 1973). This application is possible because the suspended sediment can be treated as a tracer or a marker. This permits the investigator, in principle, to trace or monitor surface circulation currents, to separate and distinguish water masses and varying near-surface sediment concentrations, and to locate and monitor sediment deposition or removal. The degree to which this can be accomplished in practice depends upon the ease with which one can repetitively view the appropriate areas, the resolution and spectral bands of the imagery available, and extent to which the

APPLICATION ASSESSMENT TABLE

TABLE II-9

Application:

Sediment

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
Identify Source, Movement, Deposition.	Spatial, spectral and temporal data. Particle size and concentration.	Probably fairly easy to determine movement and deposition of sediment. Sediment is a vehicle to determine circulation dynamics.	Limitation - problems of coordinating overpass with unusual and improtant event (flood, for example). Difficult to estimate particle size and concentration.

various image analysis techniques, such as band ratioing, contrast suppression or stretch, etc. can be quantitatively correlated with sediment as to type and load.

In the case of Cook Inlet, Alaska, for example, aerial imagery was acquired with two 9-inch formate RC-8 metric cameras at a scale of 1:40,000 and an RS-14 infrared, two channel scanner (3-5.5 and 8-14 micron) from the NASA NP-3 aircraft. With photographic data it was possible to observe surface circulation currents, relative differences in the concentration of near-surface, suspended sediment in the estuary itself and in the river plumes debouching into it. Water mass boundaries, foam and debris lines, areas of bottom scour and sediment reworking were also visible. In addition, near shore bathymetry and tidal flat morphology could be distinguished. The IR scanner imagery resolved surface water thermal patterns and was useful in making a preliminary definition of mixing patterns and of locating sources of warm or cold water entering the inlet (Gatto 1974).

The very high resolution radiometer (VHRR) imagery from the polar orbiting NOAA-3 and NOAA-4 satellites was also employed in this comparison. The VHRR imagery is provided in the red (0.6-0.7 micron) and the thermal IR (10.5-12.5 microns) bands. Ground resolution of this imagery at nadir is about 1 km, too coarse to be of any practical use in observing sedimentation processes, although it was shown to be very useful in observing major patterns in the formation, ablation, and to some degree the movement of sea ice.

The multispectral scanner (MSS) imagery provided by Landsat 1 which has a ground resolution of about 70 meters was highly useful. Of the four Landsat 1 and 2 bands, the forms and processes of most interest in the investigation and monitoring of sedimentation phenomena are best shown in the red (0.5-0.6 micron) and near infrared (0.6-0.7) bands. The satellite passes over Cook Inlet on four successive days in the 18-day cycle and can record three scenes of the inlet on each day. Cloud cover and low sun angle were found to restrict the aquisition of useable imagery more than 80 percent of the time, however. Thus, the inability to reliably obtain systematic repetitive coverage is a serious limitation. Despite this limitation, within a year sufficient imagery had been obtained to permit a detailed assessment utilizing ground and sea data

provided by survey parties, instrumented buoys and crews aboard the NOAA and University of Alaska Marine Institute oceanographic research vessels.

Qualitative descriptions of surface currents near river mouths were easily derived from Landsat bands 1 and 2 from the shapes, successively observed at various tidal stages, or river plumes where freshwater entered the inlet. Somewhat increased resolution would aid this application but is not absolutely essential. Distinctions between the clear oceanic water masses entering the inlet from the Alaska current near the Barren Islands and the waters of varying suspended sediment concentrations in the estuary itself were also relatively easy to observe and follow. In a water body of this size, again, the 70 meter resolution was sufficient in general. This, of course, would not be the case always and, in general, a resolution of at least 20 meters would be desirable. In order to observe sediment removal at maximum water velocities during tidal changes, resolution of about 1 meter were required. This was achieved using aerial imagery. Zones of water mixing and circulation patterns could be identified from the Landsat imagery alone from the shape and behavior of the suspended sediment patterns. These were subsequently confirmed by actual measurement and observations.

The formation, ablation and movement of sea ice in Cook Inlet was easily observed. Much of the ice was observed to be deposited on the tidal flats at low tides and stacked in refrozen layers as much as 12 meters in thickness. Ice floes are distinguishable from frazil ice and windrowed stringers were observable.

In terms of the most important activities affected by sedimentation in Cook Inlet, an economic criterion would immediately identify fisheries, the establishment and maintenance of navigation routes and the maintenance of harbors and small boat basins. The dispersal of pollutants, other than sediment, is another important factor to consider. <u>Satellite imagery is not being used on a systematic basis to aid in any of these tasks</u>. It has been used instead, either on a one-time basis or sporadically, in response to a special need. Dredging and harbor maintenance are continually required in all major harbors. As many as 5,000 man years may be involved at a total annual cost of as

much as $0.2 billion per year. It is conceivable that savings of $2 million per year could be achieved by improvements in selecting dumping sites and in defining sediment sources from satellite imagery of sufficient quality. Presently available Landsat imagery is adequate for early regional surveys.

3. Impact of Landsat follow-on

Regional analysis of tidal flats is quickly and conveniently accomplished by comparing bands 4 and 7. Detailed analysis is limited by the 70 meter resolution. Improved resolution would greatly increase the usefulness of the Landsat MSS imagery for this purpose; at least one meter resolution is needed.

For monitoring sedimentation processed about a four-fold increase in resolution is required and improvements in the use of digital data are needed. These consist of improvements in computer processing and display, for the most part, but the establishment of quantitative correlations between sediment type and load and the respective spectral signatures are needed for each locality where the application is to be made. It is desirable to be able to penetrate the cloud cover in many localities, particularly in the North; an imaging radar might eventually be developed that would have some useful capability in this connection.

The spectral bands available are sufficient for needs at present insofar as sediment detection is concerned. Refinement will depend upon detailed comparisons and research during the next five to ten years to recognize the relationship between sediment types and their spectral signatures.

In general, the Landsat 1 and 2 MSS is superior to the RBV sensor. The RBV being placed on the Landsat C platform will have improved resolution, comparable to that of the Landsat 1 and 2 MSS. Therefore, the images from cameras 1 and 2 are expected to be adequate to accomplish most of the objectives discussed above since they cover the spectral range required.

The Landsat C MSS imaging device is identical to that on the two preceding vehicles except for a fifth spectral channel covering the thermal IR (10.4-12.6 microns). The instantaneous field of view of this band, however, is expected to be about 200 meters, about three times that of the other four channels. Nevertheless, this band is

expected to be very useful. It should aid in defining and characterizing water masses, confirming and extending the interpretations that have been described as possible from bands 1 and 2.

Taken in the aggregate, the improvement over Landsat 1 and 2 offered by Landsat C and Landsat follow-on for this application is insignificant except for the addition of the thermal IR channel. The increment of improvement represented by this addition, cannot be very well estimated at this time. It is unlikely to significantly affect any of the activities associated with removal and control of sediment and sedimentation, respectively. However, the potential for improving the management of fisheries may be great.

4. Continuing Issues

Continuing issues that must be addressed are: (1) Improve the provisions for technology transfer within user agencies and organizations. Of course, this is primarily a responsibility of these institutions but NASA should recognize their need to achieve a greater awareness and participation among the various units within their organization. (2) Additional research and development is required to facilitate the use of the required imagery in digital form, bypassing, as much as possible the necessity for hard copy prints except when deliberately selected for one reason or another, as the format of choice. (3) Research is needed to develop and optimize the imaging processing and enhancement techniques required for this application. This includes the development of algorithms and numerical models that can accept the data on sediment type and concentration contained in the various spectral signatures.

I. ESTUARINE DYNAMICS

1. Background

An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage (Cameron and Pritchard, 1963). The interaction of the fresh and sea water is a function of the mixing processes resulting from density differences of the two waters. The circulation dynamics are the result of a number of complex factors, including salinity, temperature, coastal currents offshore, tidal components, upland discharge, estuarine bathymetry and

configuration, as well as winds and the nature of the salt water/ freshwater interface.

According to Dyer (1973), "The main drawback in studying estuarines is the river flow, tidal range and sediment distribution are continually changing and consequently some estuaries may never really be steady-state systems, they may be trying to reach a balance they never achieve."

This continuing dynamic variability of the estuaries is precisely the reason why satellite observations are so necessary for monitoring the estuarine circulation. These perturbations are not readily predictable except in those rare cases where numerical or physical models have been developed. Reliable numerical models (and physical models) can be prepared on as a consequence of a series of detailed surveys and measurements, which are costly and time-consuming.

The present state of the art in estuarine dynamics allows us to use numerical models, which in some cases are reinforced by physical, hydraulic models such as the large model of Chesapeake Bay built by the Army Engineers. Numerical and physical modeling are only as reliable as the input information received.

The reasons for studying estuaries are to permit wise and optimum utilization. Estuaries are used as harbors, sources of minerals, oil well locations, recreation, sewage and waste disposal, fishing, aqua-agriculture, etc. To manage this complex dynamic resource area requires both a knowledge of the estuarine system and monitoring of that system. The study of circulation dynamics is basic to all users of the estuary. Without this knowledge flushing and diffusion are impossible to determine, and management becomes "the impossible dream."

2. Traditional Approaches

The Department of the Interior has completed a basic inventory of U.S. estuaries. But the study is not and could not have been a detailed study of the type required for modeling studies. Nevertheless, it was an important first step. The urgent national need, however, is to predict precisely and confidently the consequences of using and modifying each and every estuary.

Mapping of the land-water boundary (mean sea level) has been or is being adequately done for most estuaries. Bathymetry is likewise fairly well accomplished for the larger and port-and-harbor-related estuaries.

TABLE II-10
APPLICATION ASSESSMENT TABLE

Application:

Estuarine Dynamics

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
National inventory.	1. Basin geometry.	2	Near IR band.
Tidal current charts.	2. Bathymetry.	1	Blue band.
Extreme event effects.	3. Areal extent, high and low tide.	2	Near IR band.
	3. Thermal distribution (surface thermal map).	2	IR data (thermal).
Classification of Estuaries as to type.	4. Pollution sources (thermal and other).	2	Using thermal and plume tracers.
Circulation, diffusion, and dispersion.	5. Meteorological data.	1	Using thermal and sediment tracers.
	6. Salinity determination.	1	
Identify current patterns, pollutants, sediment, shoreline morphology, and flooding.	Spatial, spectral, and temporal data to compile information on circulation patterns, and monitoring of changes in the estuary.	Landsat follow-on should provide much needed data. The improved resolution and spectral coverage should be very valuable.	Limitations will be long periods (18 days) between overpasses -- will miss many unusual conditions (unusual low and high water, spills, sediment discharges, etc.).

However, tidal current charts are less common, and are rarely detailed. Physical models are prepared mostly by the Army Engineers and must be preceded by additional survey work. Three-dimensional dynamic modeling is rare but vital to environmental monitoring, pollution studies, flushing and estuarine circulation.

3. Impact of Landsat follow-on

Modeling of all the nation's estuaries has never been done, and Landsat follow-on by itself will not be able to meet the task. It will, however, permit synoptic coverage of the estuaries so that natural tracers such as sediment, turbidity, foam and debris lines, and-at last-120 m thermal mapping, will provide details of estuarine circulation, and surface salinity charting (where thermal/salinity relations permit).

It may be possible to characterize the estuaries by salinity structure using Landsat follow-on data, e.g.,

(1) the highly stratified estuaries, salt-wedge type,

(2) the highly stratified estuaries, fjord type,

(3) the partially mixed estuary,

(4) the vertically homogeneous estuary.

Certainly attempts should be made to determine under what conditions estuaries can be classified and to what degree their three-dimensional circulation patterns can be determined from Landsat follow-on data.

No attempt is made here to discuss the use of Landsat data for determining land use, wetland mapping, vegetation mapping and mean sea level determinations. These topics, while relevant to estuarine areas, deserve special treatment and are discussed in after sections of this report.

With the present proposed orbital crossing time (1100 hrs.) sun glint will negate the blue band's increased penetrating ability (on the TM) as the glint will "overpower" the sensor. Only surface phenomena will be observable most of the time. The problem will be disastrous to the water resources community. Unless it is changed, this one problem will obviate the TM for most estuarine research (other than surface effects).

Assuming the sun glint problem is solved, will auxiliary data be needed? The answer is "yes". It is envisioned that estuarine research will be conducted by 1) using Landsat images as a starting point for a

reconnaissance survey, which would permit the investigator to make informed judgments as to type of estuary, configuration, salinity distribution, surface circulation; 2) deciding where and how to instrument the estuary to provide the needed data in the most efficient and meaningful way; 3) comparing the results of the survey data with the Landsat data, extrapolating and interpolating with greater precision because of the Landsat data.

At this stage auxiliary data are essential. (They could, incidently be gathered by a DCS system). They are decidedly not an overkill. On the basis of the Merrimack River aircraft flights (see Figures II-6 - II-9) it appears that the 120 m resolution thermal imagery will provide a means to chart the surface salinity patterns under varying tidal and upland water discharge.

The improvement over prior satellite sensors will lie chiefly with the improved resolution (120 m) in the thermal channel. Though this resolution is important in the quest for basic data on estuarine dynamics, the thermal data represent only a partial, interim "step" toward the goal of accurate numerical modeling of U.S. estuaries.

4. Summary

Use of the TM thermal and visible channels will save money, chiefly by permitting the installation of instruments in the optimum location. This is especially true of current meters and temperature/salinity measurements. Ground truth will be required and will supplement the satellite data.

The generalized circulation dynamics of all moderately sized estuaries can probably be charted by MSS and TM data. It is in the national interest to do so. If successful, it would represent a savings of at least 5 years and $2-5 million over the cost of a preliminary ground survey of these estuaries. The benefits accruing to the communities and citizenry utilizing the estuarine circulation data must be compiled on an individual estuary basis. In some estuaries the benefits would be great, in others, miniscule. It would greatly aid environmentalists and corporate enterprise by providing an unbiased factual basis for environmental monitoring.

Additional research and facilities would be helpful in the area of estuarine research to augment the Landsat follow-on data; but the effort

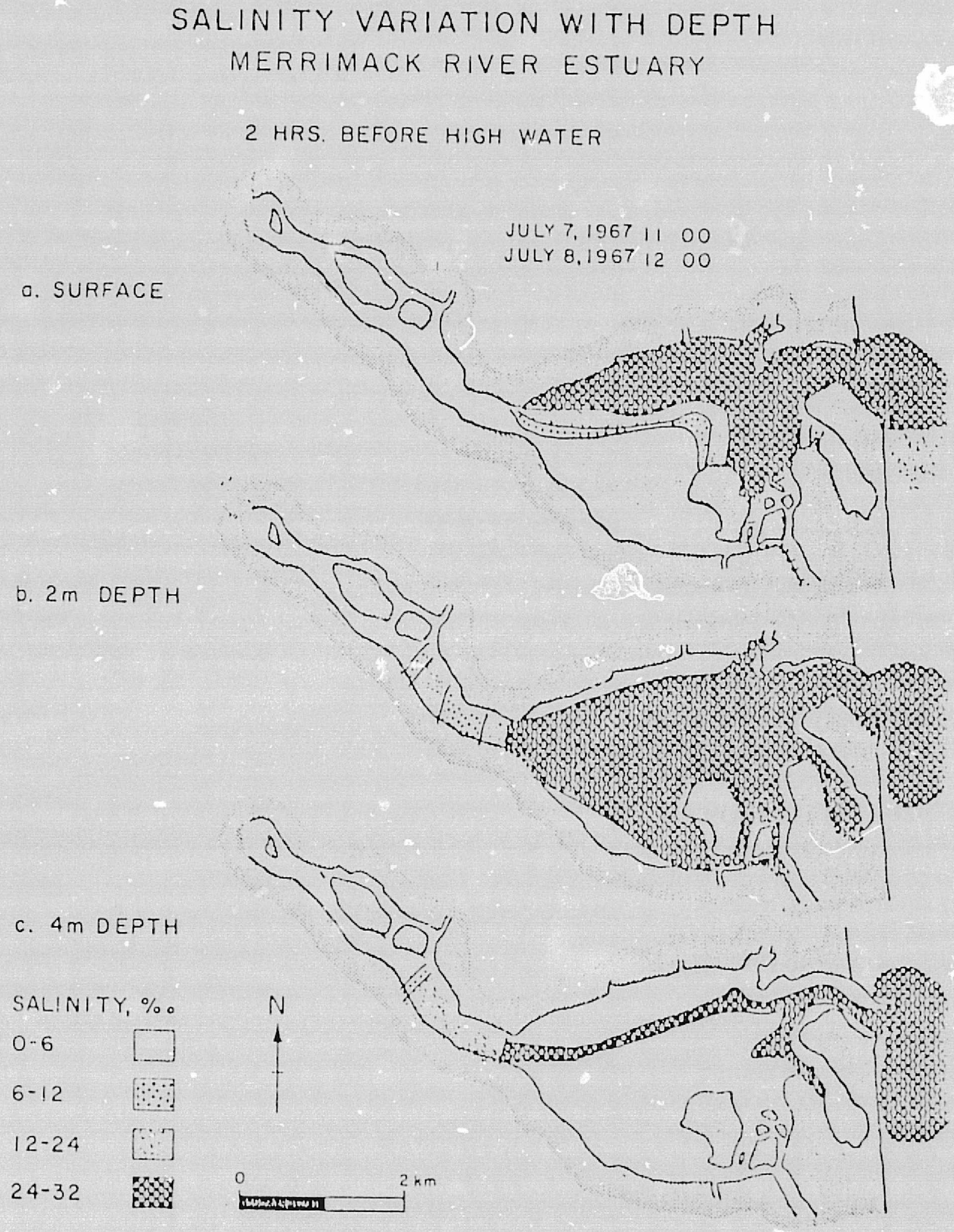

SALINITY VARIATION WITH DEPTH
MERRIMACK RIVER ESTUARY
2 HRS. BEFORE HIGH WATER
JULY 7, 1967 11 00
JULY 8, 1967 12 00
a. SURFACE
b. 2m DEPTH
c. 4m DEPTH
SALINITY, ‰
0-6
6-12
12-24
24-32
N
0
2 km

Figure II-6

SALINITY VARIATION WITH DEPTH
MERRIMACK RIVER ESTUARY

4 HRS. AFTER HIGH WATER

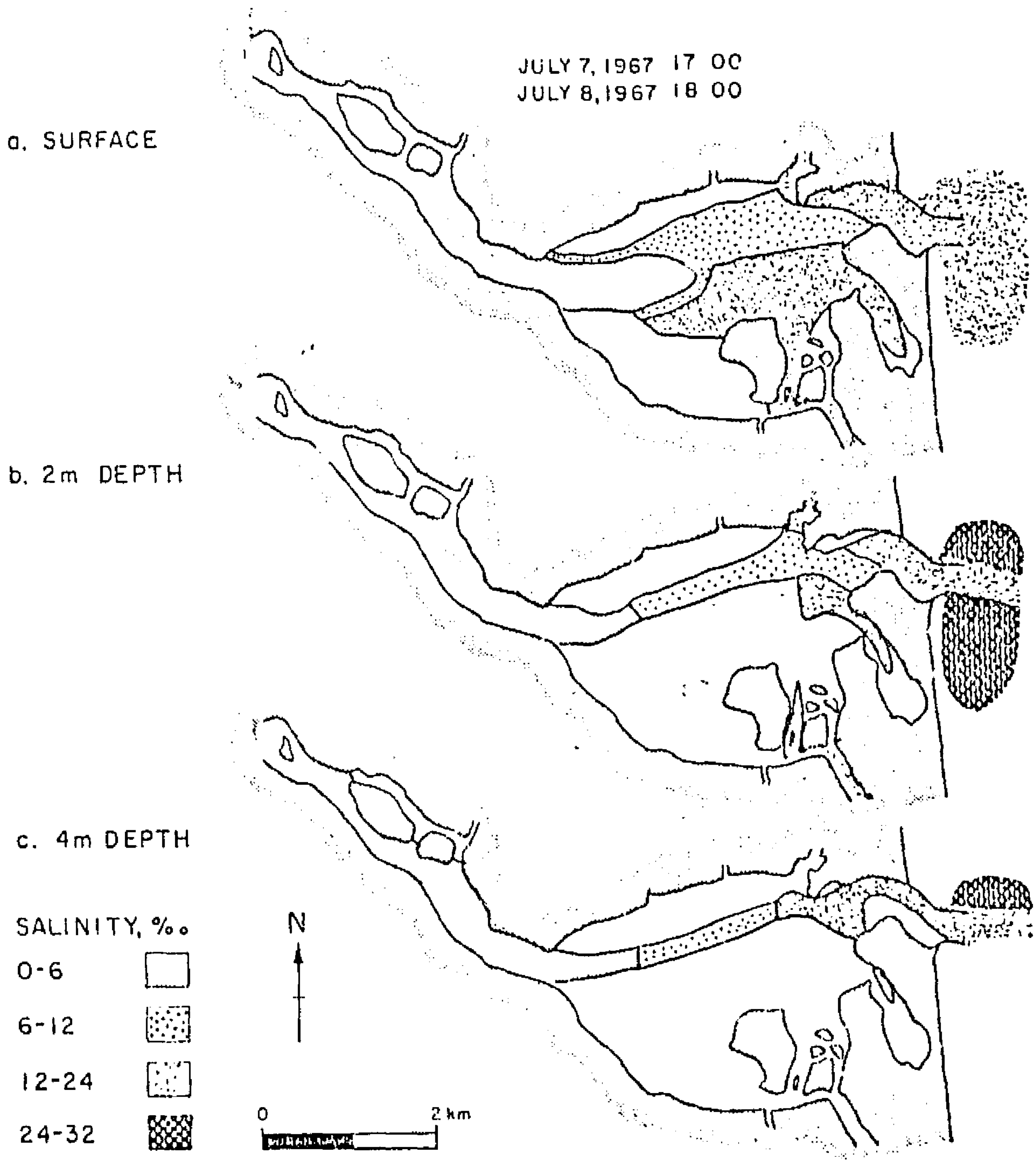


Figure II-7

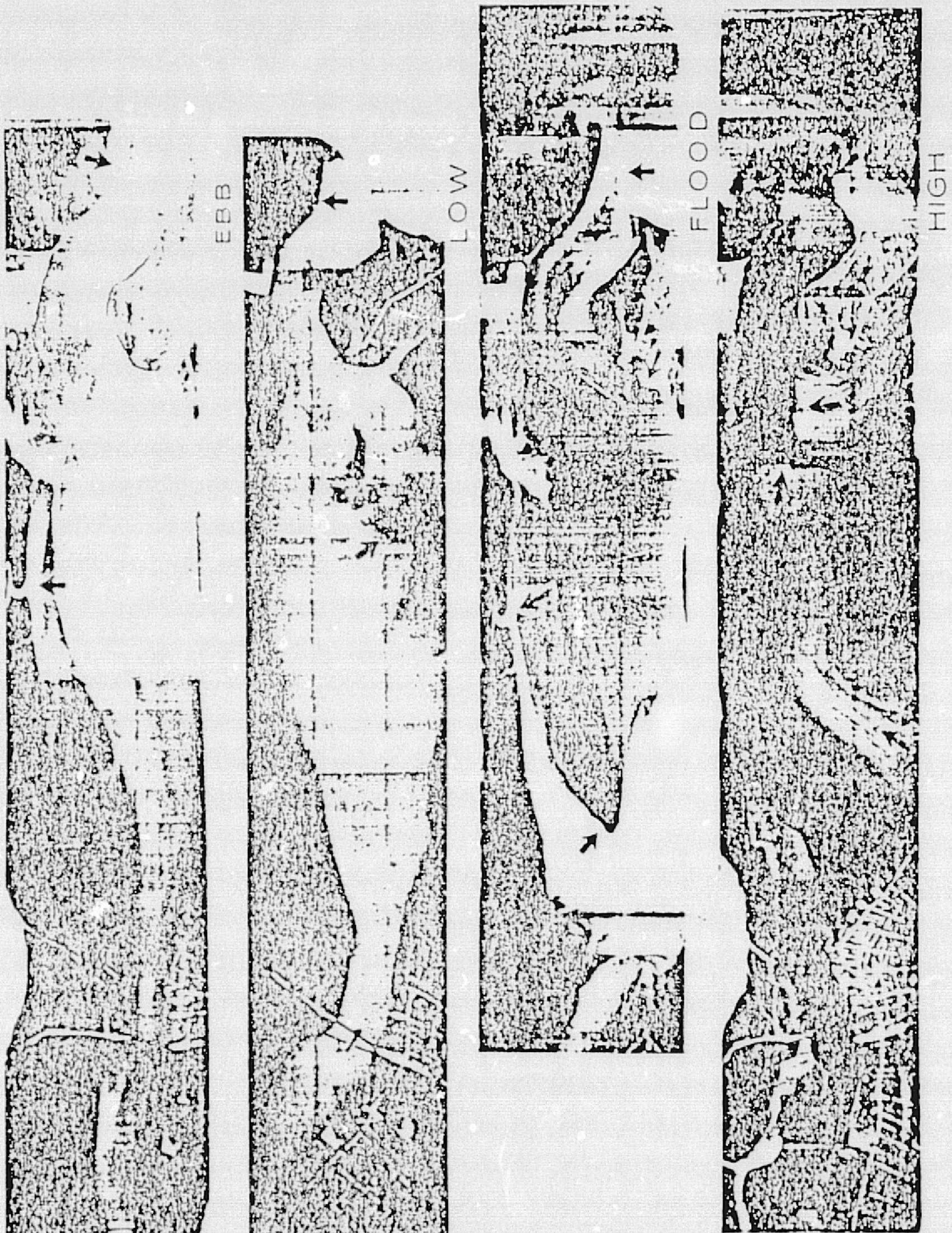


Figure II-8

Figure II-8

Infrared imagery of the Merrimack River estuary: Plum Island to Newburyport. Upstream is to the left. For orientation, see jetties on the right of the upper diagram and the city of Newburyport on the lower left of the lower diagram (Figure III-1).

Ebb: Outgoing tide at 0335, 29 September 1966. Whole estuary is full of light-colored, warm, low-salinity water.

Low-water: Low tide at 1922, 28 September 1966. Note uniform tone of the warm estuarine water throughout the entire length of the estuary.

Flood: Incoming tide at 2205, 28 September 1966. Note the surface expression of the salt water (cold water) interface. Arrow at left points to leading edge of the salt-water wedge.

High-water: High tide at 0037, 29 September 1966. Note the spreading of warm (light-colored) estuarine water over the cold ocean water, especially in the area of Joppa Flat.

(From Wiesnet and Cotton, 1967, Figure 9.)

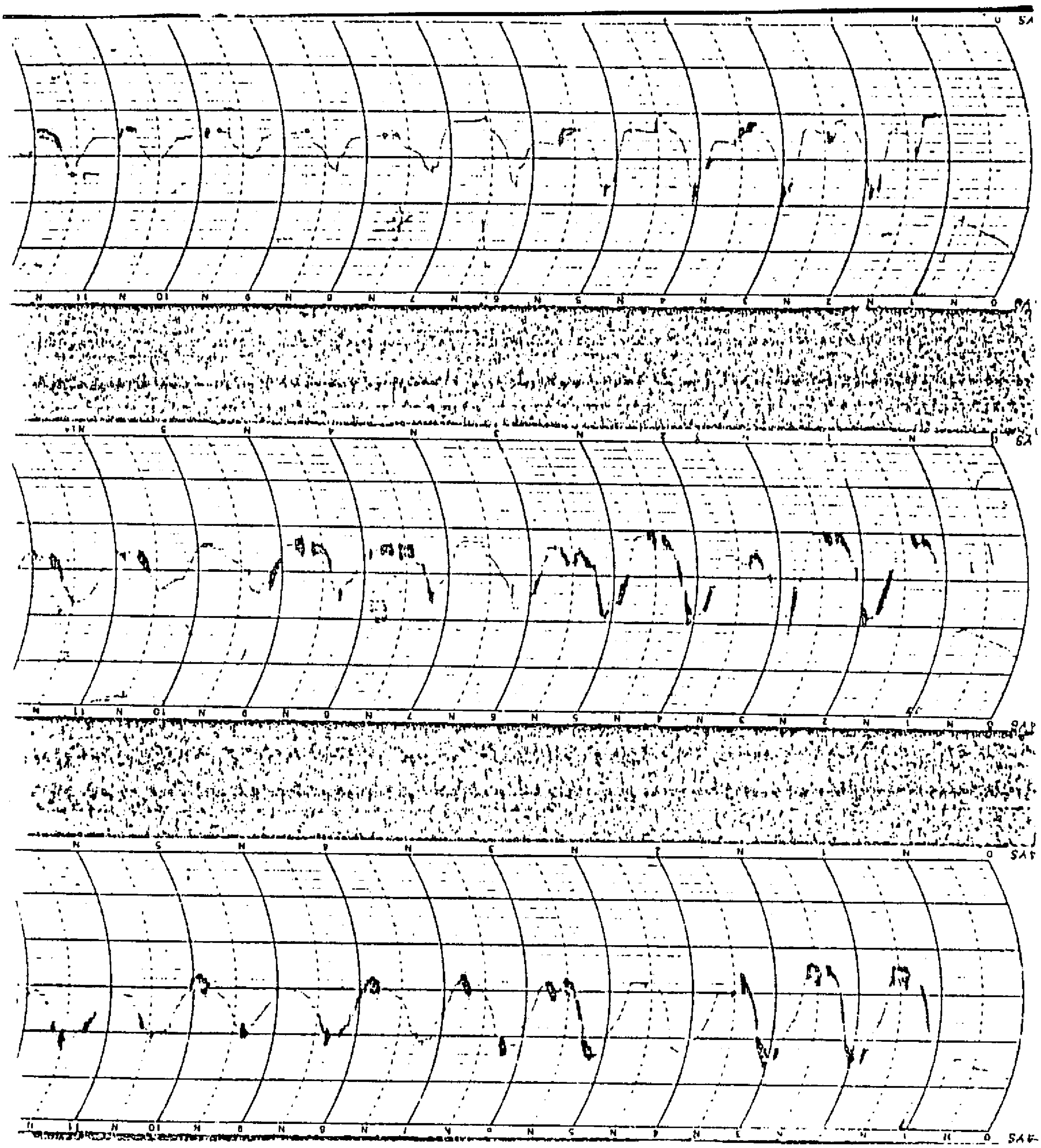


Figure II-9 Thermograph records from the Merrimack Estuary, Mass., showing the change in water temperature as the tidal currents flood and ebb (15 October 1966).

would be--ideally--on a priority basis. State coastal zone institutes would be able to handle the effort with modest expansion. The primary Federal research effort would include both Interior and NOAA with concomitant agreements. Navy and Coast Guard interests also pertain.

J. INUNDATED AREAS AND SHORELINES

1. Background

The areas of inundation included in this section are river and lake overflow, depression ponding from unusually heavy rains, and ponding in low areas because of high ground-water levels. The flooding may occur in winter or summer over urban areas, fallow farm land, crop land, wetlands, and forests. The water may be turbid, clear, or contain vegetative material that affects the spectral reflectance characteristics.

The shorelines considered here are interfaces between land and the water. In the flooded areas the shorelines frequently are indistinct because of vegetation, suspended sediment may have similar reflectance characteristics to bare ground, or bottoms of clear ponded water may be confused with land surfaces at certain wavelengths. Another condition of interest here concerns shorelines being eroded by current and wave action that results in high concentration of sediment offshore.

The delineation of flood-hazard areas can be a topic of emotional and economic concern. For example, a property owner may become very irate at seeing his property designated within the flood zone. If that delineation is accepted, a person may experience difficulty selling his property or the value of flood-hazard property may be worth only a fraction of a similar property located outside the delineated flood zone.

Objective and Scope of the Application. The purposes of delineating areas of inundation are for flood-hazard warning, to provide information for planning and development, and to reserve a needed waterway for the stream. The failure to respect nature's claim for use of the flood plain results in enormous yearly monetary losses, indescribable misery to those affected, and even the loss of life. Thus, the objective really is to minimize flood losses.

The scope of this discussion is to review conventional methods that are used to delineate flood-prone areas, evaluate the flood delineation

capability from Landsat 1, 2, and C data, and Landsat follow-on capabilities as a basis to delineate flood-prone areas. The term "flood-prone areas" is used because most stream reaches may be delineated by mathematical computation or by the identification of alluvial soils, even though no recent flood has occurred. Consideration will also be given to future needs to be addressed, such as verification work, technology development, and facilities needed to optimally use Landsat follow-on data to delineate flood-prone areas.

There are several levels of accuracy and verification requirements to be considered for delineation of flood-prone areas. A Director of Public Works may need a very accurate delineation as a basis to approve or disapprove a site plan for a building. If his decision were to be based upon satellite data he probably would want data having about a 10 meter ground resolution and the delineation backed up by actual field verification. If he should disapprove of a building plan, he may be required to defend his decision later in court.

A second level of accuracy would be similar to the needs for the flood-prone mapping program. The primary purpose of those maps was to quickly identify areas subject to flooding, without regard to detailed accuracy that can be provided later by engineering studies (Edelen, 1973). Perhaps the range of acceptable ground resolution for this purpose would be about 50 meters or better. (That estimate is based upon the comments of several Landsat investigators, previously cited, that generally claim mapping from Landsat data is applicable to scales of 1:250,000 and possibly 1:100,000.

A third level of accuracy would be for a quick assessment of damage to agriculture (Benson and Waltz, 1973) and possibly for disaster relief (Robinove,). Those authors based their studies on Landsat 1 and 2 data and the approximate 100 meter ground resolution seems adequate for that purpose.

Wiesnet and others (1974) mapped the inundated areas of the 1973 Mississippi River flood from the NOAA 2 satellite. They suggested that the 1 km ground resolution was useful to provide a daily record of the flood in a general way.

2. Traditional Approaches

Plane-table surveys have been the typical method used to delineate the inundated areas, although the data may be published as a flood

profile (distance and elevation). This type of survey is very reliable, it usually is accepted as evidence in court cases, and ancillary information may be compiled as a part of the survey. However, the surveys are time consuming, costly, and a hydrologic analysis of peak-discharge magnitudes usually is needed to determine the return period of the flood. The delineation applies only to that historic event. It may not represent the design flood for planning purposes. Also physical conditions of the basin or channel may be altered by nature or people (stage-discharge relation changed) so that the actual historic event may not be typical of future floods.

Flood-hazard areas may be delineated based upon hydrologic studies to determine selected flood peak magnitudes, field cross-section surveys, and computed water surface elevations. The profile is usually obtained through a computer solution using the step-backwater method. If done well, the solution is quite expensive and time consuming but usually is an acceptable engineering practice. The flood event is not required, the discharge magnitude desired by the planners can be used, and the computed profiles are usually not as reliable as a delineation based upon actual high water marks. In other words, nature provides a more accurate solution than people.

A third solution is the use of remote sensors from aircraft. Preferably the photographs, or other data, should be obtained at the flood peak. If such data (flood stage and imagery) are properly documented by time and hydrologic analysis, the information may provide an acceptable basis for decision. However, if the aircraft data are obtained after the peak, the investigator may have to prove that the delineations based upon those data were thoroughly verified by field inspection in order to obtain court acceptance. There is a wide choice of sensor combinations and platform altitudes available so that the investigator can minimize data bulk and maximize information content. For best success with this type of survey, the aircraft and sensors should be in a standby status and readily available to collect the data at the flood crest.

Although it is usually easy to delineate flood and shoreline boundaries (land-water interfaces) from various types of remotely sensed data from aircraft, problems can exist for all or some of the sensors.

For example, vegetative cover may obscure the boundary; when black and white near-infrared film is used where high sediment concentrations exist, the interface may be difficult to detect; and the thermal radiation from land and water may be equal and the interface may not be detectable. These problems usually are rather infrequent and are mentioned to suggest that the investigator must use good judgement in planning the mission.

a. Flood-Prone Area Maps. The 89th Congress (1966) in House Document 465 recommended preparation of flood-prone maps to assist in minimizing flood losses by identifying potential flood-prone areas. That Document suggested that the U.S. Geological Survey prepare the flood-prone area maps. This program, described by Edelen (1973), was initiated in 1968 but modified in 1969 to show the delineation for the 100-year flood-peak discharge. As of March 1976 about 12,000 quadrangles (7 1/2 and 15 minute) have been delineated. About 1,000 more quadrangles will soon be delineated to complete that phase of the project (Edelen, G.S. Jr. oral communication). Edelen (ibid) listed four methods commonly used to estimate the 100-year flood boundary as: 1) regional stage-frequency relations, 2) profiles of theoretical floods of specified frequency, 3) profiles of observed floods, and 4) aerial photographs of flooding. In most applications of the above four methods, a fairly simple analysis is required to modify flood elevations to the desired flood frequency (100-year return period).

b. Frequency of Delineation of a National Basis. The National Program for delineating flood-prone areas was intended to be a single project and not repeated (Edelen, oral communication). However, flooded areas undoubtedly will continue to be delineated by conventional means where there is an interest and need to obtain that type of information. It should also be realized that data from satellites continue to be acquired on a routine basis and occasionally a serious flood is recorded. Those data could be reduced and a delineation made at any time; however, the opportunity to verify the delineation may pass in a short period of time after a flood.

c. Time and Cost Consideration. There is a wide range of time and cost required to delineate flood-prone areas, depending on the intended purpose of the delineation and the techniques used. The flood-prone

delineation of about 12,000 maps has been accomplished for about \$7,000,000, funded under House Document 465 and the Department of Housing and &rban Development (HUD). Although the bulk of this work has been done by the USGS, information compiled by the U.S. Army Corps of Engineers and other state and Federal agencies has been used. Also, the Soil Conservation Service has prepared 417 maps that will be published as a part of the program. Flood survey information was used where available but it would have been impossible to accomplish the study from field surveys because (1) high water marks were usually not available on most of the streams of interest, (2) time was not available to wait for floods to occur, and (3) the surveys would be very costly even if the high water marks were available.

The delineation involved in the flood-prone mapping program (about \$600 per quad sheet) probably represents a minimum amount for such a product prepared by using methods other than those based upon remotely sensed data. The cost of this delineation is but a fraction of what it would have cost to have made a more detailed delineation by using the step-backwater method.

3. Role of Current Landsat Program

During recent years, satellite data have been used to delineate inundated areas (Hallberg et al., 1973; Morrison and Colley, 1973; Deutsch and Ruggles, 1974, Wiesnet et al., 1974; Williamson, 1974, Rango and Anderson, 1974; Moore and North, 1974; and Benson and Waltz, 1973). These delineations are relatively inexpensive to obtain, the data are very compact, a histroic record of conditions pertaining to the flood such as flow dynamics and dike breakage may be identified, and it should be possible to make the data available quickly for a preliminary assessment of flooding and possibly estimates of agricultural damage (Benson and Waltz, 1973). The main problems concern low resolution, timing of the flood event relative to a satellite overpass and cloudy overhead. Unless there is extensive field verification, it is doubtful if a delineation, based only upon satellite data, would be acceptable in court. Thus, the application has been demonstrated but the utility of the delineation has not been established.

The present delineation of flooded areas, based upon Landsat 1 and 2 data, probably would provide products of somewhat similar purpose to

APPLICATION ASSESSMENT TABLE

TABLE II-11

Application:

Inundated Areas and Shorelines

Information Needs (ground features to locate and evaluate)	**Parameters** (kinds of evidence in imagery, for "information needs")	**Feasibility** (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	**Remarks** (evidence experience problems, etc.)
Separation of Land from Water	Spectral and spatial discrimination of water vs. land.	Should provide fairly good results.	The delineation should be verified adequately so that an engineer can testify in court that the water boundary has been correctly shown. The more frequent the better.

that of the "flood-prone maps." The delineations using Landsat data generally have been at 1:250,000 scale, although other (smaller and larger) scales have been used. Rango and Anderson (ibid) experimented with various scales, including a comparison between a delineation based upon Landsat data for the 1973 Mississippi flood and a 1:250,000 scale composite made from 10 USGS 1:24,000 scale flood-prone maps. The authors commented that the conformity was generally fairly good although some differences existed. They pointed out that the 1973 flood may have not been equivalent to the 100-year discharge magnitude shown on the flood-prone map. The authors attributed some of the differences to effects of dikes and others to possible errors on either the Landsat interpretation or the flood-prone map delineation.

Although several investigations that have delineated inundated areas from Landsat data report good verification comparison, the application should have futher testing to determine where the techniques are applicable, what problems exist and how they can be overcome, to test the die-away of spectral characteristics of inundated areas after the flood has receded, and to obtain statistical measures of the accuracy of the delineation. Perhaps the reason for the lack of thorough verification is the scope of the verification effort required, the need for rapid work of the verification teams, and lack of funding to accomplish that work.

Another technique that should be tested is to delineate flood plains based upon the reflectance characteristics of alluvial soils and/or vegetative growth on the flood plains. Soil scientists are generally able to identify alluvial soils and have used this as the basis to delineate previously flooded areas (Oliver R. Carter, SCS, oral communication). Rango and Anderson (ibid) stated that soil differences can be identified on Landsat imagery and used as indicators of lowland soils that may be susceptible to flooding. Dallam, et al, (1975) also used this approach to delineate flood prone areas on the Pautuxent River, Maryland, using data from U-2 aircraft and Landsat. Baker, et al, (1975) reported that they were able to distinquish the boundary between upland physiography and the active flood plain. Again, the limitations and potential of this application of theme extraction needs to be evaluated. The point is that at least a certain amount of flood-plain information

(areas in flood, areas previously flooded and alluvial areas) is available for the identification of flood-prone areas and flood dynamics analysis.

Perhaps the delineation based upon satellite data may not be possible along many stream reaches, especially streams having small drainage areas (<50 sq km), but where the data are applicable, the delineation can be made quickly and inexpensively. The May 4 and 5, 1973 Landsat orbital paths imaged about 2,000 km of the Mississippi River between Cairo, Illinois and the Gulf of Mexico during a period of about 7 minutes (Deutsch and Ruggles, 1974). Those data were processed in several renditions, including a "temporal composite" that depicts both the pre-flood and flood condition (two points in time). Deutsch (oral communication) thinks that they probably could repeat the needed data processing and delineation at 1:250,000 scale for $20,000 ± a few thousand depending upon the care taken and extent of data search. Thus, delineation from satellite data is inexpensive and quick to do when good data are available.

Flood-Prone Areas from Orbital Platforms. The typical spatial, spectral, and temporal advantages of satellite data apply to the delineation of areas of inundation. The record may be in an analog and/or digital format. Other advantages are that a historic record is established for future delineation and analytical use. For example, it may be possible to trace the movement of the flood wave downstream, depending on the time periods between data collection and the magnitude and discharge time of the flood or other factors such as dike breakages. The delineation may be accomplished quickly and inexpensively, the data are near-orthographic, and digital data can be processed by computer.

The problems may include adverse weather conditions, poor ground resolution, sensor failure, overgrowing vegetation, confusion of spectral characteristics with other categories such as moist, dark soil or floating vegetation, atmospheric attenuation effects, and delays in receiving the data during or shortly after a flood.

Several of these problems can be overcome. For example, spatial resolution can be improved (Landsat follow-on), spectral capabilities can be improved (Landsat follow-on), and the frequency of coverage can be increased (more satellites or geostationary orbit). Microwave

frequencies can be used to penetrate clouds and overcome other obstacles (Seasat imaging radar is to have a 25 meter ground resolution). Considering these and other proposed technological advancements, the delineation of flood-prone areas on certain streams from satellite data appears feasible and should be considered as an alternative method if a program is initiated to update the flood-prone maps.

4. Impact of Landsat follow-on

The spectral data of the thematic mapper planned for the Landsat follow-on mission should be a big improvement over the Landsat 1, 2 and C systems with respect to spectral selection and spectral and spatial resolution. The 1.55 to 1.75μm and 10.40 to 12.50μm spectral bands should provide additional information useful to identify the boundary of water-land interfaces. The spectral capabilities of Landsat 1 and 2 have been very useful, especially the value of band 7 to discriminate between land and water. Also, the 1.5 to 1.75 band probably will be useful to discriminate between cloud shadow and water bodies, a problem on some Landsat data.

The 30 meter ground resolution of the Landsat thematic mapper (120 m for the thermal band) should provide the basis for a map product at an accuracy comparable to the previously mentioned flood-prone maps. It should be recognized that this applies only where the Landsat follow-on can sense a near 100-year magnitude flood at its peak. Based upon several investigators cited previously, the delineation should also be fairly reliable if the data are obtained only a few days after the flood. A delineation based upon the spectral reflectance characteristics of alluvial soils has not been fully tested and that application is uncertain at this time. The problems of cloud cover and vegetative overstory may interfere with the delineation of certain floods and stream reaches, respectively. Thus, the application of Landsat to provide a basis for delineating flood-prone areas appears feasible but the random nature of floods as to timing and location may mean that it will take many years to complete a national program.

Because of this, the delineation from Landsat follow-on data probably will be a hit or miss process, except for conditions of broad area floods such as those resulting from hurricanes. Considerable time and study will also be required to extrapolate specific flood to that

representing a 100-year peak discharge. It should be recognized that data from satellites represents general information and field observations probably will be needed to establish the actual boundaries.

5. Continuing Issues in Landsat follow-on

Even though the Landsat follow-on data may not be reduced for delineation of flood-prone areas immediately, those data become a historic file of flood information that may be stored for future access and reduction. They also are available for comparison between floods that occur at different times.

There are other spin-offs relating to flooding that may occur from the Landsat follow-on data. These include the determination of variables that may be used to describe storage and attenuation of flow in the flood plains. For example, Hollyday (1975) used a "riparian variable" that is really a measure of the flood-prone areas and is related to overbank storage. Jackson and Ragan (1975) used Landsat data to determine percentages of drainage basin imperviousness and other land-use parameters in hydrologic models to simulate runoff from urban areas.

There are also water and shoreline conditions that need to be identified and anlyzed that may not be caused by river overbank flooding. Wetland areas can be flooded from a rise in the ground water table to that above the land surface and lakes may have a seasonal or other cyclic variation. Higer , et al, (1974 and 1975) developed a water management model to assess the available water in the storage areas and throughout the Shark River slough of southern Florida. Although Landsat 1 and 2 have been satisfactory for this purpose, the improved spectral and spatial capability of Landsat follow-on very likely will improve an investigator's ability to delineate boundaries between land and water. There is little reason to believe that the Landsat follow-on capabilities will result in an overkill for this task.

6. Additional Facilities Needed

There have been important advancements in remote sensing technology during the past 10 years. Although Landsat data are available at relatively low cost, there are problems (time, money, and equipment) of reducing the data quantitatively, leading to the production of meaningful products. For example, the reformatting of digital tapes to obtain accurate geometric positioning for temporal comparison of picture

elements is time consuming and costly. Also, the equipment needed to process those digitized data are not readily available to most investigators and are expensive to use. The development of remote sensing t- .nology into operational programs probably is constrained because users may have difficulty processing the data. Williamson (1974) demonstrated the application of Landsat digital data processing to delineate flooded areas but, perhaps because of the large areas involved and the expense of data processing, most flood delineation studies from Landsat data have used optical techniques.

7. Future Considerations

The use of Landsat follow-on data to delineate inundated areas should be an improvement over the use of Landsat 1 and 2 data. However, there probably will be times and certain stream reaches where it will not be possible to reliably identify a previously flooded area even with the follow-on data. Additional verification studies may do much to encourage acceptance and warn of limitation of this application for identification of inundated areas at a flood peak, after the flood peak, or the identification of flood-prone areas based upon alluvial area identification. The comparative value of digital and analog processing techniques to delineate inundated areas probably should be examined. However, it may be advisable to reconsider the change to the 11:00 a.m. equator crossing time to assure that the data will not be affected by solar specular reflection during midsummer. An effort should be made to quickly process the data for field use to aid in disaster relief and permit easy field verification of the delineated areas of inundation. High water marks deteriorate quickly with time.

K. RIVER FORECAST PROGRAMS

1. Background

In order to appreciate the problems of applying satellite information to river forecast problems, it is necessary to briefly review the river forecasting situation as it exists in centers such as the Sacramento River Forecast Center.

River forecasting involves all aspects of the hydrologic cycle that can assist in determining the flow regimes which can be expected in rivers and streams. This analysis includes the influx of mositure into

the target area as represented by meteorological measurements and as amplified by real-time satellite intelligence such as that available on the GOES Satellite System. This influx of moisture must be converted into real-time and forecasted precipitation volumes. The determination of precipitation rates is accomplished through land-based precipitation sensors which serve to measure precipitation at the orifice positions of the precipitation gages. The conversion of this intelligence into precipitation data over a river basin requires the inclusion of wind and topographic effects which can seriously alter the precipitation distribution in those areas which are not measured by real-time precipitation gages.

2. Traditional Approaches

The most effective process for accomplishing this objective is the application of a tightly gridded meteorological model which is continuously tuned to the observed precipitation rates in order to establish a physically based realistic technique for evaluating non-measured areas. See also the discussion on ground water in this report for other aspects of the problem. The application of the moisture model to the basin must be separated into areas in which precipitation falls as liquid water and areas in which it falls as snow. The precipitation reaching the basin's surface must then be processed through algorithms which represent the conditions at the basin surface. In higher elevations this frequently requires snow ablation analyses in order to evaluate whether falling precipitation will add to existing packs or, if liquid water, will percolate through existing packs. In both snow and nonsnow areas, a land moisture algorithm is required which maintains an accounting of both shallow and deep soil moisture conditions reflecting both the water bound by capillary forces and free water conditions within the soil as well as the varying areas of the basin that are impervious to water. These considerations generally require a determination of soil moisture to significant depths. In the eastern United States, where precipitation is usually frequent during the growing season, the soil depths which are dominant in the integration of moisture conditions within the soil profile extend to fairly limited depths. Frequently, considerations of soil moisture are only required

in the upper five feet or so of the soil mantle. In some arid regions of the United States soil moisture conditions must be analyzed to depths of 50 to 100 feet in order to properly assess the effects of new precipitation inputs and basin runoff responses.

In order to correctly evaluate the distributed nature of snow and precipitation into a streamflow simulation model (a basic tool to forecasters) it is necessary to have a well-distributed input algorithm which can adequately reflect the varied nature of snow or liquid precipitation in terms of space and time. Any attempt to utilize a lumped algorithm which makes a simple snowmelt split, perhaps based on the area of snow coverage, causes a marked loss of intelligence and seriously decreases the effectiveness of the river forecast product.

River forecasting is a continuous process. The determination of snow conditions, soil moisture conditions, precipitation conditions, and evaporation conditions, must necessarily be handled in such a manner that accounting can be current and in a form that can be readily extrapolated using forecasted or assumed future meteorological sequences. In order to accomplish these objectives the data base must be of a continuous nature. In California telemetering systems have been designed to continuously feed the modeling systems necessary input data by reporting from field sites whenever a change in status of the field sensors occurs. The justification for continuous measurement is based upon the value of water in an environment whose economy is seriously affected by the availability of water as a resource. An error of one-tenth of an inch of runoff depth generated from inadequate sensing or untimely sensing can, over an area of 1000 square miles, produce a volumetric error in excess of 5000 acre-feet. Since water as a resource has a value which in terms of its multiple applications can generally be expected to exceed $20 per acre-foot, the nominal error of one-tenth inch can actually be an economic error in excess of $100,000.

Quite obviously a significant land-based continuous data system can be justified to support economics of such a magnitude. With the application of land-based data systems which maintain good continuity of measurement, the constraints which must be met by a remote sensing system become quite extreme. As an example, in mountainous areas of the West the definition of the percent of snow-covered area in a basin

(which is one of the most effective measurements made by satellite sensing) is only appropriate for volumetric forecasting if well-supported by a surface measurement system. Such a system, however, generally makes satellite intelligence unnecessary. In those areas where relationships between snow-covered areas and water supply volumes have been made, the correlation effectiveness of such analyses is generally poorer than that of elementary statistical relationships between surface precipitation gages and the runoff volumes. Hydrologic models can extract additional information from additional land surface data. But they can utilize snow-covered area information, which is basically a very gross measurement in terms of hydrologic modeling processes, in only a very cursory manner. For some years the Sacramento office of the National Weather Service has received information on snow coverage in the American River basin in an attempt to include it as an operational tool for river forecasting. It has been of little value for this particular use.

These comments obviously apply only where an active river forecasting program has been developed. Generally this means that where river forecasting has significant economic value, the supplemental snow level information from satellite data adds little to existing information and must be interpreted with great caution. The satellite is an effective reconnaissance device for use where land-surface measurements are not available.

3. Role of Landsat and Landsat follow-on

The indications are that snow-covered areas can be utilized to represent a seasonal water supply only under very limited circumstances. Such circumstances occur in a late-season forecast when little subsequent precipitation can be expected, and there has already been a period of significant melt so that fringe snow of relatively small depth has been eliminated from the satellite returns. In the event that the procedure is attempted at other times, grossly misleading results can be produced. Thus the satellite data is generally appropriate only to a late season situation. However, the procedures used for regular forecasting purposes and to meet the operational requirements of water managers require an accurate analysis of snowpack conditions at a much earlier date than that time at which satellite data can make a quantitative contribution, and the data base which supports such an analysis supports a more

effective continuing evaluation than is feasible with snowline information from satellites. Thus, regardless of the areal discrimination, unless satellite or ancillary data can continuously provide the actual volumetric content of the pack, its condition and its spatial distribution, that data which can be obtained from satellites for operational river forecasting must be considered of minor importance.

With these comments on the most readily observable components of satellite output, we can now comment briefly on other remotely sensed components which are being considered. In hydrologic modeling, a leading aspect which must be evaluated is that percent of the basin which is effectively impervious and contributes to immediate streamflow. This determination can be approximated by satellite measurements. It can also be approximated by measuring precipitation over river basins from storms of small magnitude when the soil mantle is basically dry and determining what fraction of the precipitation reaches the basin outlet. This allows computation of the effective impervious fraction that is needed for hydrologic models. The impervious area measured from the satellite may not necessarily be contiguous with effective stream channels. There can be misanalyses which render the satellite determinations significantly less effective than the intelligence gathered from measurement of precipitation and runoff under dry soil conditions. This particular factor (impervious area) is one of those components which is generally considered to be among the higher resolution variables possible from satellite readouts. The point is that the degree of resolution from satellites, although perhaps quite appropriate for identifying total impervious areas, may not reflect the impervious components which will affect streamflow. Consequently it may be misleading. Other components of hydrologic models dealing with soil moisture must be measured in such a way that they correspond to the operating system needed to make extrapolations into the future. These hydrologic prediction systems, which necessarily represent considerable depths of the soil mantle, are extremely difficult to evaluate by remote sensing. At this time there are no indications that remote sensing capability can provide as much information as a few widely scattered surface measurement stations.

This analysis of the limitations of satellite data has been reached somewhat reluctantly. The author has been, and continues to be, involved in projects designed to assess the hydrologic potential of remote sensing in real-time hydrologic applications. To date the results have been quite discouraging. The primary element which appears appropriate as input into existing hydrologic systems and which seems achievable through satellite sensing, relates to changing patterns in land use which cannot be readily modeled through past historic data but which need to be inserted into the system to maintain an effective, continuing river forecast capability. Land use patterns do not generally change significantly with such rapidity that satellite intelligence would be better than ground-based intelligence in terms of defining these characteristics. However, in those areas where rapid changes in land use patterns do occur most dramatically through natural catastrophies such as forest fires, the satellite provides a useful and valuable tool in assessing the changes which can be expected in the modeling system when a major change in basin characteristics occurs. This does not require extensive modification of Landsat capability, and is attainable with current readout equipment to the degree that such information can be translated into useful hydrologic information.

Another consideration in river forecasting involves the evapotranspiration within a basin and the changing stress on plant life associated with changes in soil moisture conditions. Unfortunately satellite readouts of plant stress are significantly affected by immediate conditions of temperature, dewpoint, radiation and wind speed in addition to the soil moisture conditions. It is quite possible for a plant to indicate a stress circumstance with a relatively wet soil if atmospheric conditions or apparent evapotranspiration conditions by color signatures from plants is not as reliable as an accounting system based upon hydrologic modeling and a few surface sensors.

The remote sensing of hydrologic data with respect to snow and streamflow forecasting does not appear to this correspondent to be of an adequate capability to compete with land-based sensors. It is basically two-deminsional in nature, while effective hydrologic forecasting is three-dimensional and requires a more discrete data base.

At this time satellite resolution gives some information as to the distribution of flow patterns in large water areas. The more pressing problems for the river forecaster is the evaluation of possible eroding of levees or channel movements during major flood circumstances. At times when this information would be of greatest value, that is during heavy rain circumstances, remote sensing of surface conditions is most impractical. Once again, the necessity in a real-time circumstance is for a continuous, reliable data flow which is unimpaired by weather conditions. It should be appreciated that satellite data is basically too gross to fit the operating mode in those areas where river forecasting has significant economic value. Thus it would appear that only in the areas where economic and public safety value of river forecasting is not great, might satellite intelligence be used in lieu of a more expensive surface data collection system. This circumstance, however, does not exist in much of the contiguous United States.

The numerous correlations and analyses which have been performed by those evaluating the capabilities of remote sensors have applied only to special cases and circumstances which are only portions of the continuing river forecasting role met by modern hydrologists. Where appropriate river forecasting capabilities have been developed, the survey type of data available by remote sensing is of a significantly lesser accuracy than that which is economically necessary in consideration of potential damages from flood circumstances.

L. REQUIREMENTS AND ROLE OF THE DATA COLLECTION SYSTEM

1. Background

The U.S. Army Corps of Engineers has played a significant role in the development and management of the National water resources systems. The Corps primary functions have been related to flood control, water supply, hydropower generation, navigation, and beach erosion control. In addition, the Corps is also responsible and interested in disaster assistance, administrating Section 404 permits, providing estuarine forecasts for navigation interests, recreation pool maintenance, sport fishing maintenance, and data distribution to other agencies for management of water oriented activities.

As a general procedure, the development and management of water resources systems entail planning, engineering, construction and operation process. Additionally, research and development programs are also required to support the above mentioned functional areas. One of the most important factors needed for successfully carrying out the tasks of each of the functional areas is the availability of data. Depending upon the individual function, the type, nature, and the time and space scale of the data required for each category vary to a large extent.

2. Data Requirements and Collection

The hydrologic parameters required for planning, design construction and operation of the Corps projects generally consist of:

- Precipitation
- Snow Depth
- Ice Thickness
- Evaporation - Transpiration
- River Stage
- Reservoir Water Level
- Depth of Water Table
- Soil Moisture
- Air Temperature
- Dew Point Temperature
- Wind Speed and Direction
- Incoming Solar Radiation
- Water Temperature
- Specific Conductance
- Dissolved Oxygen
- PH
- Turbidity
- Tide Stage

The requirement of time scale for each individual parameter depends on the intended use of the particular data type. Historical data collected at intervals of hourly, daily, weekly or monthly are generally used for project planning and design of dams, reservoirs, navigation facilities, recreational facilities, floodplain management plans and other hydraulic structures. For the purpose of reservoir regulation, decision making and flood fighting real-time data must be provided. Real-time data of

precipitation, river stage, reservoir level and tidal stage etc. are being provided to mathematical models that attempt to predict river conditions, and optimize the operation of water resources systems. For planning and design usages a data interval of hourly to daily is acceptable, whereas for real-time application a data interval of less than 3-hourly is more preferable.

Conventionally historical data that are used by Corps offices for planning and design were collected by other governmental agencies such as the USGS and NOAA. Real-time data, however, have been largely collected by the Corps itself. This type of data collection system is generally installed at major project sites. The Fort Worth District, for example, has responsibility for warning those responsible for emergency mobilization in the event of floods. Shorter response time and increased accuracy in all aspects of data collection and forecast generation will allow faster and more efficient implementation of these tasks, resulting in considerable savings in life and property. Cost savings to the Government will be realized in being able to direct personnel to the exact area where they are needed.

Hurricanes recurringly strike the Texas coast with great devastation. It can be expected that one hurricane or tropical storm occurs every year. The Texas Coast will experience on the average one hurricane every other year and a tropical storm every third year.

The Galveston District works on a different philosophy than the Fort Worth District with respect to their hydrologic operations because of their different responsibilities and geography. Basically they work as a self-supporting entity in terms of hydrologic data from collection to forecast generation and dissemination. Consequently their engineers are much more involved with data manipulation than are those in the Fort Worth District. The only outside data they receive, other than that from the Fort Worth District, are those from the NWS pertaining to hurricane locations and winds and the River Forecasting Center of NWS peak stage predictions on upper streams.

Both Galveston and Fort Worth Districts and Tulsa District are in the stage of reviewing their current water information management and control systems. Data acquisition and management automation systems are being designed.

3. Role of Landsat and Landsat follow-on

The New England Division has been evaluating the utility of the Landsat data collection system for the past two and a half years. Twenty-seven platforms have been operating in parallel with the 41 station ground-based Automatic Hydrologic Radio Reporting Network which is the present backbone for flood control reservoir regulation activities at the division. The Landsat data collection platforms have been reliably transmitting such information as river level, precipitation, air temperature and water quality to the division's Reservoir Control Center. The satellite platforms also have been operating successfully in remote areas, demonstrating the suitability for using satellites to economically acquire data previously unattainable from these sites.

The Jacksonville District, in cooperation with the USGS, has been receiving Landsat relayed hydrologic data for almost 3 years from 9 different locations in central and southern Florida. The information is received at the nearby USGS office by way of a teletype link with the NASA ground receiving station at Greenbelt, Maryland. Jacksonville personnel have found the data to be reliable and are now utilizing this system operationally. The launching of NOAA's Geostationary Operational Environmental Satellite (GOES) makes both periodic and real-time data transmission closer to reality. At present, the Lower Mississippi Valley and North Pacific Divisions are planning to undertake experiments in relaying hydrologic data using the GOES system.

a. Cost Effectiveness. The investigations indicate that costs for data relay by satellite can be less than those for ground-based systems. For example, the New England Division's ground-based Automatic Hydrologic Radio Reporting Network had an initial cost per station in 1969-70 of $20,000. This includes all equipment for the total system (i.e., transmitters, antennas, 4 relays, 12 repeaters and the central control facility with an IBM 1130 computer for data read out and processing). The division estimates the initial cost of an operational orbiting satellite data collection system to be between $5,000 and $10,000 per data collection platform location. This figure is based on 2 satellites, 10 ground receiving stations and 2,000 platforms nationwide. The cost per platform would be lower if more were installed. Cost estimates are not yet available for a GOES system.

A questionnaire sent to all Corps offices in July 1973 found that, over the next 5 years, nearly 4,500 data collection locations will be needed Corps-wide for the relay of hydrologic information for water management activities.

b. Future Prospects. The Corps data requirements to be derived from remote sensing have been identified and are listed below:

(1) Land cover--identification of type and location of land cover and, where possible, land use. Categories include urban, rural, agricultural, vegetation, natural resources, wetlands, and surface water. These data can be updated to monitor land cover change. Applications for this approach include location of waste-water treatment sites, relationships between land use and pollution type and load, relationship of land use to socioeconomic data, location of land sites for dredge disposal, and others.

(2) Littoral processes--identification and monitoring of water circulation patterns, sedimentation rates and patterns, shoaling, bottom profiling, wave mechanics, sand inventories, and coastal erosion and deposition location and rates. Applications for this approach include physical and mathematical model verification, near shore and offshore construction requirements, identification of areas requiring dredging activities, location of beaches requiring sand replenishment, and others.

(3) Subsurface water--identification of location, route, and flow patterns of water below the surface of the ground with use of surficial and subsurficial geology, vegetative cover, and soil moisture as indicators. Applications include identification of areas of seepage around and/or through structures, drain tile locations, water-table definition for land acquisition requirements in reservoir planning, levee stability, and others.

(4) Water quality--identification of salinity, dissolved oxygen, conductivity, turbidity, temperature, and organic substance in water bodies. Applications include assessment of eutrophication or suspended sediment in water bodies, adequacy of reservoirs to support recreational activities, and others.

(5) Geology and soils--identification of rock type and genesis; igneous, metamorphic, and sedimentary; relationship of type and depth

of overburden to parent material; location of fault size, type, and activity; mapping of caves, caverns, and sinkholes; identification of Pleistocene formations (kames, drumlines, moraines, etc.); identification of drainage patterns; and delineation of limestone formations. Applications include dam locating, road route selection, dam stability evaluation, construction materials location, definition of constraints to construction, and others.

(6) Environmental impact--identification of predictive or evaluative factors in nature that have been or will be impacted by land use activities and construction projects. Applications include project siting, effect of fluctuation of water level on vegetation, influence of strip mining on erosion, monitoring coastline conditions for permit awards, and others.

(7) River engineering--identification of limits of backwater areas, river alignment, river flow patterns and rates, transverse and longitudinal surface sediment distribution, velocity fields, bed form effects, assessment of the physical vulnerability of natural and man-made structures. Applications include definition of construction requirements in river systems (riprap, bed form structure), dredging requirements, flood abatement structures, improvement of natural and manmade levee systems, location of areas of high erosion potential, identification of dredge-disposal sites, and others.

(8) Flood plain mapping--mapping extent of flooding waters and identification of flood plain features that represent flooding frequency interval boundaries. Applications include flood plain management, flood protection control, flood plain surveys, pre-flood damage potential assessment, post-flood damage assessment, spillway management, setting up priorities for areas requiring disaster relief, and others.

(9) Runoff prediction--identification of distribution and quantity of snow cover, assessment of snow water content, determination of soil permeability, and evaluation of the potential precipitation of clouds. Applications include prediction of runoff potential, determination of storage capacity and release rates in reservoirs, flood damage prevention, and others.

(10) Data communication--utilization of ground-based data collection platforms that report river stage, rainfall, information on

coastal winds and tides, water quality parameters, and snow depth. These data are relayed by satellite-to-ground receiving stations several times daily and transmitted back to the user on a near real-time basis. Applications include the definition of reservoir stage-storage relationships, supplement or replacement of existing microwave data collection systems with a more cost-effective satellite system, prediction of runoff potential, warning mechanism for water quality degredation, and others.

(11) Digital processing--development of use of computer for interpretation, display, and storage of remotely sensed data. Input includes computer-compatible tapes, scanner data, thermal data, photographic data, and data collection platform recordings. Output includes alphanumeric products, film reader and writer products, calcomp plotter products, computer cards, results for correlation and regression studies, and others.

(12) Ice mapping--mapping location, extent, and movement patterns of ice bodies. Applications include location of navigation hazards, prediction of rise in water levels, and others.

Finally, the Corps and NASA have initiated a program within the context of NASA's Applications Systems Verification Test. This is a three-phase study project. The purpose of this project is to investigate the feasibility of using remote sensing technology to assist in calibrating hydrologic models. Calibration data that may be amenable to remote sensing technology include cultural features, land use/infiltration characteristics, soil moisture content, and degree of imperviousness. If the potential is realized, the ability to easily monitor rapidly changing land use due to increasing urbanization could be exploited to identify important urbanization parameters and the extent of their impact on hydrology.

M. STREAMFLOW MODELING

1. Background

With the advent of computers and the resulting capability to mathematically represent complex dynamic systems, modeling techniques for large water resources systems have developed. River basin models are used as a management tool to make decisions related to such things

as optimum use of water with consideration of requirements for flood control, power, navigation, recreation and wildlife. Models of this nature are used for the Columbia River basin in the Northwest and the Salt River project in Arizona as examples. Major river basins in the United States are managed by either the Corps of Engineers or Department of Interior, state agencies or combinations of these agencies. All major river basin management systems rely on modeling results in their decision making process.

2. Traditional Approaches

Models of large systems can accommodate relatively large errors in estimates of flow from local areas of the system and still produce acceptable results at the lower end of the basin. The river basin models are generally based on relatively sound historical records of stream flow when the basin is located in a developed country. The major inadequacy for such models is the lack of reliable estimates of water stored in the higher elevations as snow. The uses and benefits of the basin models could also be increased if adequate models could be used to predict the flow of water from all the subareas of the basin. Most of the tributary watersheds that would be considered subareas do not have historical records of streamflow; therefore, techniques for modeling ungauged watersheds are necessary before this type of system can be placed in operation. For tributary areas, computed estimates must be more accurate as the systems respond quickly to storm rainfall. To predict the flood volumes and peak flows in small watersheds, simple empirical equations have been commonly used by practicing hydrologists. More complex models (Stanford model, Haltons model) have been recently developed in attempts to more adequately describe elements of the hydrologic cycle on a continuous basis. With the current state of the art in hydrology these more complex models can rarely be applied to a watershed area without extensive detailed records of rainfall, land use, soils, geology runoff, etc. for use in calibration of the model.

Coefficients for the empirical watershed models to represent the combined surface characteristics (soils, vegetation, slope, etc) of the drainage area are determined in a subjective manner and are dependent on the experience of the hydrologist. As the models become more complex, the number of coefficients increase and variables are used that are difficult to measure in a quantitative sense.

3. Role of Current Landsat Program

Remote sensing techniques offer an opportunity to provide an objective estimate of coefficients for both types of watershed models and can provide reliable estimates of such input variables as land use, drainage density, water surface area, etc. Further refinement and modification of existing models to accommodate remote sensing data will likely make mathematical modeling of previously ungauged watershed areas a reality. An experiment with Landsat data (Blanchard, 1975) has shown that the coefficient for the simple empirical watershed runoff model used by the soil conservation service can be estimated by using reflectance of visible and near-infrared light from the watershed surface. Estimates of the coefficients based on Landsat data were compared with coefficients arrived from measured storm rainfall and runoff as well as coefficients determined in the conventional manner. The remote sensing technique produced more reliable values than the conventional technique; furthermore, the technique was found to be repeatable when surface conditions were relatively dry and vegetation was dormant.

Monitoring of snow and frozen earth is an important factor in improvement of modeling for watersheds. In many areas where water resources are of vital interest, a major portion of the water comes in the form of snow. Until the spaceborne sensor systems were developed, the spatial distribution of snow has been difficult and sometimes impossible to measure. Studies (Salomonson et al.) with Landsat data have demonstrated that these data can be of great value in measuring areal extent of snow.

In other work (Ragan 1975) the classification of surface reflectance using Landsat data has been used to identify and map the impervious areas within a watershed. This accomplishment, along with the development of numerous techniques for classification of agricultural vegetation, provide input to empirical formulas used to predict peak flows. Other empirical models are also available to estimate long term yields of water supply. These also require some mapping of surface characteristics to provide estimates of impervious areas and areas where varying levels of surface or near surface storage is available.

Another approach to hydrologic modeling involves prediction schemes based on the physical dimensions of watershed characteristics. Such measurements as stream length, stream channel classification and length-to-width ratio of the drainage area can more readily be acquired from multispectral scanner data when large areas are involved. In most instances, these measurements can be made from spaceborne remote sensing data for less investment in both time and money.

Conventional techniques for estimating watershed storm runoff coefficients are subjective and sometimes result in unreliable values. As a result many hydrologists tend to increase the estimates to insure safety in the design of flood control structures. This action results in unnecessary added costs of construction and in the case of impoundments in semi arid regions leads to excessive evaporation and degradation of water quality.

The improvement in accuracy of Soil Conservation Service watershed runoff coefficients resulting from the use of digital Landsat data has been demonstrated. This in turn results in improved estimates of flood volumes used as the principal criteria for designing the size of flood control works, highway bridges and culverts etc. The more accurate estimates of flood volumes will also aid in improved management of water storage in impoundments.

Considerable improvement in flood warning and management models for large river basins can conceivably be developed as a result of the ability to classify the runoff potential of small areas. Conceptual models in which each sub area of a watershed is treated as an independent watershed have been successfully tested by the Agricultural Research Service of USDA. These models were developed on highly instrumented research watersheds. For most watersheds there is no objective method of classifying the runoff potential of each sub area. This classification can now be accomplished by using the SCS runoff coefficient determined from Landsat data. The technology is available for routing stream flow through stream networks and impoundments with the aid of computer programs. The influence of flows from all portions of the river basin could then be combined to produce a more sensitive watershed model based on remote sensing data from all the ungaged sub areas within the basin.

APPLICATION ASSESSMENT TABLE

TABLE II-12

Application:

Runoff Modeling and Basin Physiography

Information Needs (ground features to locate and evaluate)	**Parameters** (kinds of evidence in imagery, for "information needs")	**Feasibility** (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	**Remarks** (evidence experience problems, etc.)
Watershed Area	Texture, patterns.	Improved	
Land Cover	Texture, patterns (digital data).	Improved	
Stream Network	Texture, patterns.	Improved	
Soil Type	Tonal variation (in some areas), vegetation.	No Change	
Slopes	Landform, Topo.	No Change (perhaps worse because of 11:30 crossing time).	

Preliminary models using remote sensing data will be available for public use by the time the Landsat follow-on sensor is in operation. More elaborate models will be in the development stage and with the addition of thermal data, the output of models should improve. The thermal bands will make possible more meaningful linear combinations of data. The soil-air interface is a critical portion in the hydrologic cycle and the temperature of the surface can lead to an estimate of the antecedent moisture of the watershed surface. At the present state-of-the-art, combining thermal data from NOAA satellites with the Landsat data is not practical and resolutions are not compatible. The advent of concurrent thermal data and the availability of improved resolution will in turn bring about improvements in the measurements already tested as input to the SCS Watershed runoff watershed models.

It should be pointed out that the current resolution of Landsat is adequate for use in watershed planning where empirical equations are used. The improved resolution and band wavelength of the thermatic mapper is likely to increase the value of classification schemes. Improved classification would provide opportunities to measure variables for the more complex models.

The measurement of antecedent moisture conditions is probably the most significant contribution to complex watershed models that can be developed from the addition of thermal data. At present there is no method of identifying the residual soil moisture between widely spaced weather bureau rain gages. The thermal data on a temporal basis should indirectly indicate the spatial distribution of wet and dry surfaces. If wet areas can be mapped prior to additional rainfall the potential for high runoff can be recognized. Mapping wet and dry areas will also enhance present estimates of evaporation and evapo-transpiration used in the comple watershed models.

Data from experimental watershed study areas with intensive raingage networks have shown wide variation in storm patterns in areas subject to thunderstorms. There is no technique available for identifying the actual storm pattern from the conventional raingage network; thus even a relatively poor measurement of storm pattern may prove worthwhile. Identification and measurement of many other watershed characteristics addressed in other portions of this report contribute in some way to the river basin models.

4. Impact of Landsat Follow-on

The dollar value of improvements to input for these models will be difficult to evaluate since complex modeling is in a continuing developmental state, however, modeling techniques are recognized by hydrologists as the only hope for answering the nation's need for water resources planning information.

It is the author's opinion that the development and testing of watershed models using remote sensing data has progressed rapidly after the launch of Landsat 1. Development of new applications of remote sensing in water resource mkdels should increase with the increasing availability of data and training of personnel. Constant development and testing will be necessary to gain the full benefits from the addition of spectral bands, the availability of temporal data and concurrent improvement in mathematical modeling. Testing new models and incorporation of data from the thematic me per can radily be done on a university level while demonstration of promising applications should be planned under an ASVT program.

N. URBAN HYDROLOGY

1. Background

Tasks Performed by Urban Hydrologists. The planning, analysis, design, and management of urban water resource systems is recognized as a specialized category of hydrology. For simplicity, the term "urban hydrology" will be used in this report. The tasks performed by the urban hydrologist range from the very detailed to the very broad. Table II-13 (McPherson, 1970) summarizes the overall activities in urban water resource management.

Some phases of these tasks require such detail that the use of Landsat remote sensing is not possible. Still, the planning, management, and preliminary design of activities associated with these tasks do allow remote sensing with Landsat to be a valuable tool. This is especially true in the larger metropolitan complexes where the problems involve areas larger than several square miles. Even though it is generally assumed that a well organized metropolitan area has current land use maps available, this often is not the case. Thus, Landsat cover delineations are very attractive

TABLE II-13

ASPECTS OF METROPOLITAN WATER MANAGEMENT ACTIVITIES

Urban water uses:

- Water supply (domestic — including drinking water, commercial, industrial, agricultural and for fire protection);
- Conveyance of wastes (from buildings and industries);
- Dilution of combined and storm sewer system effluents and treatment plant effluents (by receiving bodies of water);
- Water-oriented recreation (and fish management);
- Aesthetics (such as landscaped creeks and ponds in parks and parkways);
- Transportation (commercial and recreational);
- Hydropower generation; and
- Dissipation of heat from thermal power plants.

Protection of urban areas from flooding:

- Removal of surface water at source (by conduit systems or canals);
- Conveyance of upstream surface water through the area (by conduit systems or canals);
- Barricading banks, detaining or expressing flow of natural streams to mitigate spillover in occupied zones of flood plain (by levees, dikes, upstream storage or canalization);
- Flood warning and "dynamic" flood-proofing of structures; and
- Flood plain management.

(continued)

TABLE II-13 (continued)

Manipulation of urban water:

- Groundwater recharge (using processed water or stored surplus surface water);
- Recycling of water (reuse of effluents for water supply, recreation, etc.); and
- Low Flow Augmentation (water transportation, water supply, etc.)

Pollution abatement in urban areas:

- Conveyance of sanitary sewage and industrial wastes in separate sewer systems;
- Interception and treatment* of sanitary sewage and industrial wastes (from separate sanitary sewer systems or dry-weather flow from combined sewer systems);
- Interception and treatment of storm sewer discharges or combined sewer overflows (by means of detention storage facilities);
- Reinforcing waste assimilation capacity of receiving water bodies (by forced aeration, low-flow augmentation or other means, to raise ambient dissolved oxygen content);
- Treatment of sanitary wastes at point of origin (household and building treatment plants);
- Disposal of sludge from treatment plants; and
- Interception of runoff of mineral sediments from construction and natural areas.**

(continued)

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*: A Primer on Waste Water Treatment, FWQA, U.S. Dept. of the Interior, GPO, Washington, D.C., October, 1969.

**: Community Action Guidebook for Soil Erosion and Sediment Control, by M.D. Powell, W.C. Winter, and W.P. Bodwitch, National Association of Counties Research Foundation, Washington, D.C., March, 1970.

TABLE II-13 (continued)

Water-Land Planning: -

- Water as a controlling influence on residential development and on transport and industrial loca .;
- Reduction of peak drainage runoff rates by proper land-development design;***
- Utilization of the "blue-green" development concept, employing ponds with open space, for storm flow detention and recreation, to enhance urban property values and decrease property depreciation rates, thereby increasing long-term tax revenues;*** and
- Pursuit of long-range planning which incorporates community social values inherent in dynamic historical, physical and biological processes, responding to real variabilities of the environment, realizing both opportunities and limitations for human use, while utilizing the concept of complementary land use and identifying least-social-cost locations for development.****

Interfacial public services:

- Snowstorm and rainstorm traffic routing;
- Street cleaning scheduling;
- Snow removal strategies;
- Lawn irrigation conservation; and
- Air pollution control.

(For a general discussion of some of these aspects and their interrelationships see: Water as an Urban Resource and Nuisance, by H.E. Thomas and W.J. Schneider, Geological Survey, U.S. Dept. of Interior, Water in the Urban Environment Series, Circular 601-D, GPO, Washington, D.C., 1970).

*** : "Urban Hydrology — a Redirection," by D. Earl Jones, Jr., Civil Engineering, August, 1967.

****: "What Would You Do With, Say, Staten Island," by Ian McHarg, Natural History, Journal of the Museum of Natural History, Vol. 78, No. 4, April, 1969.

tools. For example, water supply forecasting can be done at the preliminary planning level with land cover maps that indicate population distributions developed from Landsat studies (LARS Milwaukee Study).

Inventories for planning studies and parameter estimates for modeling are responsibilities that are common to each of the tasks listed in Table II-13. For simplicity, subsequent discussion will center on these inventory and parameter estimating responsibilities. The problems associated with these two responsibilities are similar regardless of whether we are discussing a project concerning water conveyance, site selection for a treatment plant, or flood control. The specific parameters would differ in each case, but the basic strategy associated with the inventory and parameter estimation responsibilities would remain the same.

2. <u>Application of Tasks</u>

a. <u>Local Applications</u>. The inventory study is the initial step in any planning operation. Its function is to identify the problem and determine the major factors that may be causing the problem. No intelligent forecasts can be made or alternate courses of action selected without knowledge of the current state of the system being planned. An inventory study will assemble all the pertinent information relevant to the present and proposed state of the system. Table II-14 adopted from Bauer shows the relative position of the inventory responsibilities as part of the overall sequence in urban water resource planning.

Environmental concerns and increasing conflicts on the use of limited resources has led to the development and utilization of complex, computer-based models as part of the planning process. All of these models require input parameters that are generally based on land cover. The advantage of a model having parameters defined in terms of land cover is that it allows experimentation with alternate forms of development and the assessment of future changes that might occur. The basic approach is to calibrate a model to reflect the hydrologic or water-quality consequences of an existing land use pattern. Once the planner is satisfied that the model is truly representative of the system, he then has a tool which allows him to experiment and evaluate the impact of changes that he might be considering. Unfortunately, estimating the parameters in terms of land cover when areas in excess of several square miles are involved is a difficult task (Huber, 1975; ASCE Ana.;

TABLE II-14
Water Resources Planning

Identification			
1. Statement of Problems and Development Potential 2. Geographic Units and Divisions 3. Analysis and Forecast Requirements 4. Scope and Intensity of Necessary Inventories 5. Objectives 6. Standards 7. Principles			Formulation of Objectives & Standards
8. Channel Capacity and Basin Traits 9. Flood Stage Traits and Damage	A	Hydraulic Inventories	Inventories
10. Rainfall Runoff 11. Water Budget 12. Streamflow and Flood Frequency 13. Geology and Ground Water	B	Hydrologic Inventories	
14. Ground Water 15. Stream Water 16. Lake Water	C	Water Quality and Use Inventories	
17. Existing Land Use 18. Public Utilities 19. Community Plans and Zoning 20. Economy and Population	D	Socio-Economic & Physical Inventory	Inventories
21. Wood Lands, Wet Lands and Wildlife 22. Soils 23. Parks and Open Spaces 24. Conservation Practices	E	Land Related Natural Resource Base Inventory	
25. Public Finance and Organization 26. Water Law	F	Legal & Fiscal	
27. Aerial Photography 28. Base Mapping	G	Cartography	
29. Future Plan Runoff Loadings 30. Future Water Quantity Demand 31. Future Low Flow Conditions	H	Water Related Factors	Analyses and Forecasts
32. Future Water Quality Demands 33. Future Consumptive Water Use 34. Future Pollution Loadings	H	Water Related Factors	Analyses and Forecasts
35. Future Economic Activity and Population 36. Future Land Use Demand 37. Future Land Related Resource Supply 38. Future Land Related Resource Demand	I	Land Related Factors	

TABLE II-14 (continued)
Water Resources Planning

Identification	
39. Alternative Water Quality Control Facility Plans 40. Flood Routing 41. Satisfaction of Objectives 42. Simulation of Purpose 43. Flood Stage and Damage Forecasts 44. Cost/Benefit Analysis 45. Effect on Resource and Utility Use 46. Water Quality Simulation 47. Alternative Land Use Plans 48. Alternative Water Quantity Control Facilities Plan	Plan Design & Plan Test and Evaluation
49. Alternative Watershed Plans 50. Specific Review and Adoption 51. Legal Feasibility 52. Final Watershed Plans 53. Advisory Committee Review and Public Hearings 54. Financial and Administrative Feasibility 55. Flood Hazard and Land Reservation Maps	Plan Selection and Adoption
56. Plan Implementation	

Iwanski and Fitch 1975; AGU SCS paper). Further, the complexity of the sub-watersheds within an overall area is such that the hydrologist must use a model that does not require extreme detail to define the parameters. For example, Milwaukee, Wisconsin occupies an area of 246 square kilometers and has over 2,200 kilometers of storm and combined sewers (McPherson, 1970). With catch basins spaced approximately every 150 meters, one could be concerned with 14,500 inlet watersheds. This cannot be done on a systems basis. Therefore, the models that are employed in planning treat significantly larger watersheds and "average the parameters involved." Thus, Landsat, with a resolution of approximately 1.1 acres, is definitely applicable in the planning type of study.

b. Role in Overall Water Resources Management. The significance of urban hydrologic problems can be addressed in terms of the distribution of population in the United States. In 1970, there were 233 Standard Metropolitan Statistical Areas (SMSA). Briefly, an SMSA is an area centering on a city (or pair of cities with a common boundary) having a population in excess of 50,000. In 1970, approximately 70% of the population resided in these 233 SMSA's. It is estimated (McPherson, 1970) that by 1985 half again as many Americans as today will be living in the SMSA's.

Very recent changes in the birth rate and family structure within the United States no doubt cast some question concerning these projections. Still, there can be little doubt that the vast majority of the American population will continue to reside, and most of the growth will continue to take place, in the urban complexes.

Competitive uses of limited resources are most severe in the heavily populated areas. Thus, the problems of urban hydrology are complex and extremely vital. The result is that a substantial portion of the overall expenditures for water resources development are, and will continue to be, allocated to those areas of dense population. It has been estimated (annon., 1971) that the average annual expenditures by local governments on urban water resources is approximately 12 billion dollars per year. Of this, approximately 3.5 billion dollars per year is allocated to the design and construction of storm sewers. These expenditures may increase significantly if the current level of environmental concern continues.

One problem, for example, concerns the existence of older sewerage systems in which the sanitary and storm water is carried in one pipe known as a combined sewer. There is some effort to eliminate these combined sewers because of the pollution load that reaches the receiving stream during periods of rain fall. Replacement of these combined sewers is estimated at 48 billion dollars (Annon., 1975)

There are other programs such as storm water management and sediment control that are beginning to be implemented in urban areas that will require a significant increase in the level of expenditures. The design and planning responsibilities associated with these projects is much more complex than the traditional storm sewer design problems. The determination of non-point sources of pollution required by the "208 Studies" is also beginning to require significantly more sophistication in the planning steps and utilization of the models involved. All of these new concepts are already required in many areas by governmental regulations and can only increase as time goes on. The load placed on the hydrologists and engineers involved in meeting these responsibilities is becoming severe. There is not enough personnel to allow the traditional approaches to be used. Thus, a number of communities have already gone to the use of Landsat for their "208 Studies" (Rogers, et al., 197, NCA). Regional governmental organizations are also beginning to test the use of Landsat data to define the parameters needed for their hydrologic modeling and the inventory studies associated with their planning responsibilities.

3. Costs and Time Involved

Most of the inventory studies and parameter identification efforts center on field investigations, map measurements, and the use of large-scale aerial photographs. A tremendous amount of time is involved in assembling the necessary data and getting it into the proper formats. As an example, the Anacostia Resource Identification Study (Ragan, et al. 1973) conducted for the Maryland Department of Natural Resources was concerned with a 132-mile water-shed. The focus of the effort was the development of 42 transparent map overlays showing the distribution of various elements relating to the water resource. The approach was to digitize land use information obtained from analysis of one 1:4800 aerial photograph. A transparent mylar grid with points spaced two-tenths of an inch on center was overlaid on the photograph.

Nine land use categories under each of 94,000 points were defined and digitized. Ninety-four man days were required to accomplish this task. An additional 90 man-days were required to accomplish a similar task involving the identifications of the soil associations throughout the watershed.

The times cited above may at first seem excessive. The Northern Virginia Planning District Commisssion recently conducted a similar inventory for the 19 square mile, Four-Mile Run Watershed in their area of jurisdiction. Four and one-half man-months were required to develop the information. A major problem is that the land uses not only have to be determined, but estimates developed for the percent of imperviousness of each land use type so they can be used in the models. The Maryland National Capital Park and Planning Commission required two and one-half man-months to develop the parameters required for the Soil Conservation Service (SCS) model on a 21-square mile portion of the Anacostia River Basin. Huber (1975) has discussed some of the factors leading to these long time periods.

The times required to complete the individual tasks are extensive. There appear to be no data on the frequency of such studies on a national basis. One approach in developing an estimate of the times and costs involved on a national basis is to start with a consideration of the 56 SMSA's that have populations in excess of 500,000. Within these SMSA's there are 174 county governments, 2,902 municipal governments, 1,470 township governments, 3,844 special districts, and an additional 2,486 special water-related districts dealing with flood control, water supply, drainage, etc. Experiences with the counties surrounding Washington, D.C. indicate that approximately 150 man-days per year are devoted to land cover determinations and parameter estimates associated with urban water resource developments. If we assume an hourly rate of $8.00, which would include overhead and fringe benefits, this would amount to $9,600 per year for each county. If we further assume that the 174 counties represent 75% of the work being done by all the counties in the nation, it would appear that county governments are expending approximately $2,230,000 annually. Within each of the SMSA's, there is probably a multi-county council of governments (COGs) organization which does major studies. These would be large areas of

the 208 Study type. It would appear reasonable to assume that COG's could reasonably be spending $26,880 per year, which would account for a $1,500,000 annual expenditure by the 56 SMSA's. Municipal governments probably invest very little in this type of work. Therefore, it is assumed that the 2,902 municipal governments expend no more than 10 man-days per year, or $640 per organization. However, the municipal governments within the 56 SMSA's are a very small portion of the national municipal governments. Therefore, it is assumed that the SMSA municipal governments account for only 25% of the national expenditure. Therefore, it is estimated that municipal governments, nationally, are spending in the vicinity of $7,400,000 annually on studies that could be done by remote sensing. Township and special district governments represent probably a very small investment. If we assume they have no more than five days per year and, as before, that the SMSA units account for only 25% of the national, the expenditure by these township and special district governments would be in the vicinity of $4,900,000 per year.

The water-related districts probably use in the vicinity of thirty man-days per year, or $1,920 per agency. It is probable that the water-related districts in the 56 SMSA's are substantially larger than those in the remainder of the national scene. Therefore, it is assumed that expenditures of the 2,486 districts within the 56 SMSA's account for 50% of the total annual expenditure. Therefore, it would appear that $9,500,000 are being expended annually by these organizations.

If all of these estimates are summed, it would appear that $27,580,000 are being expended nationally for the inventory and parameter estimate studies associated with water resource development projects. As stated earlier it has been estimated that 12 billion dollars per year are being expended on urban water resources. Therefore, it appears that the estimate of $27,580,000 is reasonable, because this amounts to only 0.2% of the total expenditures being devoted to the land use and parameter estimate studies. As a second test, it was estimated by the American Society of Civil Engineers (1970) that 2.5 billion dollars per year were being spent for storm sewer construction. The $27,580,000

estimated for the remote sensing aspects amounts to only 1.1% of the storm sewer expenditures, which again is reasonable. Experience indicates (ASCE Ana.; Iwanski and Fitch 1975; AGU SCS paper) that approximately 4 man-days with Landsat remote sensing are required for every 100 man-days of parameter estimates using traditional approaches. These figures apply to those watershed studies that would be relevant to the figures quoted above. If one is concerned with the design of one catch basin, being a drainage area of two or three areas, Landsat remote sensing will be of no value, so this type of study was not considered in developing the estimate above. Further, four man-days are considered to be associated with machine classification from the Landsat digital tapes. A study of the Anacostia River Basin (ASCE Ana.; Iwanski and Fitch, 1975) showed that the use of air photo interpretation techniques on Landsat hard copy was of little value because of the lack of detail when concerned with urban water resource studies. It must be recognized that the four man-days with remote sensing technology are substantially more expensive on a unit basis than a 100 man-days using the traditional approach. This is because of the equipment involved and the higher technological training required of the personnel. A figure of $250 per day to process the remote sensing data is probably realistic. Using this figure, the watershed studies involved in developing the $27,580,000 expenditure could be reduced to $8,274,000 by shifting from traditional technology into Landsat technology. Again, it is emphasized that these estimates are based only on those tasks that are truly Landsat compatible. They do not include the detailed studies on very small watersheds.

4. Traditional Approaches

In urban water resource studies, much of the data has to come from sources that cannot be remotely sensed. This will probably always be the case. Data from census tract and tax maps provide inputs on population distributions and economic valuations. Although water quality in lakes can be estimated through remote sensing techniques, it is doubtful that, in the foreseeable future, water quality can be estimated within the small streams involved in urban areas. Thus, water quality information must be obtained from monitoring stations. The same is true of the stream discharges.

In the detailed analyses associated with the final steps of design, it is necessary to have maps showing the location of water distribution systems and sewage collection systems. It is not uncommon for this type of information to be almost impossible to find even though it is extremely necessary. The problem is that much of construction took place many years ago and was either not recorded or improperly recorded with the agencies. Detailed information on water supply and sewage flow must also be obtained from records maintained by the local governmental agencies. Again, this type of information is generally necessary only in the later stages of the planning process.

Much of the information used in water resource planning studies comes from topographic maps. Information on slopes, channel lengths, stream density, etc. is taken from standard USGS quad sheets. Information on channel geometry, which is required for some types of models, may have to be actually surveyed in the field. Information on soils is obtained from SCS county soil surveys when they are available.

The final design of structures involved in urban water resource projects requires rather detailed analysis of the area in the immediate vicinity. It may be necessary to use very detailed hydrologic models which require such information as length of overland flow, the type of gutter in the street, the sewer diameter, etc. This information can be estimated by using large scale, aerial photography. Color infrared photography taken with U-2 and RB-57 aircraft can be used for areas up to about five square miles. Beyond that, the time involved in analyzing the photographs and the fatigue become a problem with the air-photo interpreters when trying to get the detailed information required in some hydrologic models. Although frequently discounted, errors do result in manual interpretation of these photographs even though it appears that they have thoroughly outstanding resolution. Table II-15 is presented as an example of a confusion matrix that resulted in the classification of a 21-square mile watershed in the Maryland suburbs of Washington, D.C. The overall estimates were quite good; however, confusion among classes at specific points was quite significant. The costs associated with the use of U-2 aircraft photos is significant when large areas are involved. Presently, it costs approximately $150

TABLE II-15

CONFUSION MATRIX FOR LAND USE INTERPRETATION FROM U-2 PHOTO ON THE UPPER ANACOSTIA

	LAND USE	INTERPRETER 1: CULTIVATED	OPEN SPACE	FORESTED	RESIDENTIAL SINGLE	RESIDENTIAL MULTIPLE	PARKING LOTS	INDUSTRY/COMMERCE	BARE SOIL	TOTAL
INTERPRETER 2	CULTIVATED	223.	143.	14.	20.	0.	0.	4.	41.	445.
	OPEN SPACE	105.	382.	21.	34.	3.	2.	6.	10.	563.
	FORESTED	14.	133.	541.	46.	2.	0.	5.	6.	747.
	RESIDENTIAL SINGLE	16.	84.	32.	548.	0.	0.	30.	6.	716.
	RESIDENTIAL MULTIPLE	0.	1.	0.	5.	40.	0.	4.	0.	50.
	PARKING LOTS	0.	3.	2.	2.	0.	6.	3.	0.	16.
	INDUSTRY/COMMERCE	1.	7.	2.	17.	3.	4.	29.	1.	64.
	BARE SOIL	22.	7.	2.	3.	0.	0.	0.	72.	106.
	TOTAL	381.	760.	614.	675.	48.	12.	81.	136.	2707.

to enlarge a photo to something approaching a map scale of 1:24,000. The enlargement is necessary when using large areas because of the extreme fatigue involved when using optical transfer scopes. For example, ten man-hours were required to classify the 140-square mile Seneca Creek Watershed in Montgomery County, Maryland, into nine hydrologically related classes. This was done from 1:24,000 enlargement and simply could not have been done using a device that required constant peering through a binocular scope. Considerable success has been achieved by airphoto interpreters in the area of defining soil associations. Originally developed for black and white photography, this success prevails in the new color infrared products from the U-2 aircraft. U-2 photo pairs were used in a stereo plotter to develop soil associations with considerable success in the 130-square mile Anacostia River Basin of Maryland (Ragan, et al. 1973). Work by the Tennessee Valley Authority (TVA Paper ASP) has indicated that Landsat may be used in some areas to develop the soil associations with a success that will approach that currently possible with the air photos.

5. Role of Current Landsat Program

Table II-16 and Table II-17 show the land covers required as inputs to the SCS hydrologic model (SCS TP-55) and the Corps of Engineers STORM Model (STORM Doc.). The SCS Model has been used extensively for many years throughout the United States and abroad. The STORM Model is a recent development, but is beginning to see use and it is anticipated that its use will be widespread as a planning tool in the future. STORM is intended as a planning model and is designed to accept land uses as inputs that can be realistically obtained. Many models require such detailed input information that they are simply not applicable in areas larger than several hundred acres. As stated earlier, some of the metropolitan areas have literally thousands of kilometers of storm sewer involved within their systems, prohibiting the corresponding very detailed land cover analyses. With the exception of multi-family residential classification, the categories outlined in Table II-16 can be identified with the current Landsat.

The land use delineations outlined in Table II-16 for the SCS Model are too detailed to be economically determined except for very

LAND USE DESCRIPTION	HYDROLOGIC SOIL GROUP			
	A	B	C	D
Cultivated land[1/]: without conservation treatment	72	81	88	91
: with conservation treatment	62	71	78	81
Pasture or range land: poor condition	68	79	86	89
good condition	39	61	74	80
Meadow: good condition	30	58	71	78
Wood or Forest land: thin stand, poor cover, no mulch	45	66	77	83
good cover[2/]	25	55	70	77
Open Spaces, lawns, parks, golf courses, cemeteries, etc.				
good condition: grass cover on 75% or more of the area	39	61	74	80
fair condition: grass cover on 50% to 75% of the area	49	69	79	84
Commercial and business areas (85% impervious)	89	92	94	95
Industrial districts (72% impervious).	81	88	91	93
Residential:[3/]				
Average lot size — Average % Impervious[4/]				
1/8 acre or less — 65	77	85	90	92
1/4 acre — 38	61	75	83	87
1/3 acre — 30	57	72	81	86
1/2 acre — 25	54	70	80	85
1 acre — 20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[5/]	98	98	98	98
Streets and roads:				
paved with curbs and storm sewers[5/]	98	98	98	98
gravel	76	85	89	91
dirt	72	82	87	89

[1/] For a more detailed description of agricultural land use curve numbers refer to National Engineering Handbook, Section 4, Hydrology, Chapter 9, Aug. 1972.

[2/] Good cover is protected from grazing and litter and brush cover soil.

[3/] Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[4/] The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

[5/] In some warmer climates of the country a curve number of 95 may be used.

TABLE II-16

Land Uses from SCS-TR-55

INPUT

I. LAND USE INFORMATION

Residential
Multiple Family
Commercial
Industrial
Park

A. AREA
B. % IMPERV.
C. RUNOFF COEFF
D. FT. OF GUTTER/ACRE

II. HYDROLOGIC RECORD OF HOURLY RAINFALL

ANALYSIS

I. RUNOFF

$R = C(I-D)$

where:

$C = \dfrac{\Sigma C_i A_i}{\Sigma A_i}$

II. QUALITY

$Mp = P(1 - e^{-KR})$

A. SUSP. SOLIDS
B. SETT SOLIDS
C. BOD
D. NITROGEN
E. PHOSPHORUS

III. STORAGE

$\Delta S = R - T$

OUTPUT

I. STATISTICS BY EVENT

A. RAINFALL
B. STORAGE
C. OVERFLOW
D. TREATMENT
E. QUALITY

II. AVERAGE STATISTICS FOR ALL EVENTS

A. EVENTS/YR.
B. AVERAGES OF A-E ABOVE FOR ALL EVENTS
C. OVERFLOWS/YR. AVERAGES OF A-E ABOVE FOR ALL OVERFLOW EVENTS

TABLE II-17

STORM INPUT-OUTPUT ELEMENTS

small watersheds. It must be recognized that the model is empirically derived from a series of watershed studies that have been conducted for many years throughout the United States. Therefore, the curve numbers quoted are not unique but instead are best-fit estimates of a run-off co-efficient. Therefore, an alternate land cover delineation presented as Table II- 18 has been developed as an alternate for use in the SCS Model (AGU SCS Paper). The land cover categories in this table can be developed from Landsat. Studies conducted with the SCS Model using land cover delineations obtained from aircraft in accordance with Table II-16 compare very well with those obtained from Landsat and used in the categories of Table II-18 (AGU SCS Paper).

Table II- 19 is presented as an example of the agreement between synthetic flood frequency series developed from aircraft, ground surveys, and Landsat-determined land uses for a 21-square mile portion of the Anacostia River Basin in Maryland (AGU SCS Paper).

A rather extensive comparison of Landsat derived data with traditionally developed data for use in the STORM Model has been conducted on the Four-Mile Run Watershed in Virginia. Table II-19 shows estimates of the peak discharges obtained with a stream-flow calibrated model based on traditional input parameters with those developed from land uses derived through computer classification of Landsat digital tapes. The Four-Mile Run Study also included comparisons of the synthetic flood frequency curves using the Landsat and traditionally based STORM Models. These frequency curves are compared in Figure II-10.

A study using the Kentucky Watershed Model on a series of drainage basins was used as a basis for developing the sensitivity of the required parameters. Table II - 20 (from Annon., GSFC 1974) shows some of the requirements for maintaining errors within a specific range if the Kentucky Watershed Model is being used. It can be seen from this that the Landsat approach to land cover delineations is feasible for this model.

Some models require the stream density as one of the input parameters. It has been shown (Rango,) that stream networks in some physiographic regions can be estimated with a high degree of accuracy with the Landsat data. However, in some areas such as the Atlantic

TABLE II-18

Runoff Curve Numbers for Land Uses
that can be
Defined from Landsat CCT Analysis

Land Use Description	Hydrologic Soil Group			
	A	B	C	D
Forest Land	25	55	70	72
Grassed Open Space	36	60	73	78
Highly Imperviousness (Commercial, Industrial, Large Parking Lot)*	90	93	94	95
Residential	60	74	83	87
Bare Ground	72	82	88	90

* Probably sufficient to use CN = 93 for all soils.

TABLE II-19

Discharges and River Stages Computed
With SCS Models

Randolph Road Gaging Station on
Northwest Branch of Anacostia River

Return Period (yrs)	Precip. (in)	Discharge (cfs)			Depth of Flow (ft)		
		TR-20	LANDSAT	U-2	TR-20	LANDSAT	U-2
2	3.0	2,990	3,490	3,850	8.9	9.3	9.6
5	3.3	4,610	5,140	6,064	10.0	10.4	10.9
10	5.4	6,210	6,900	7,580	10.9	11.3	11.7
25	5.8	7,390	8,759	9,300	11.7	12.3	12.7
50	6.7	9,020	9,900	10,400	12.5	13.0	13.3
100	7.3	10,780	11,100	11,806	13.5	13.6	14.1

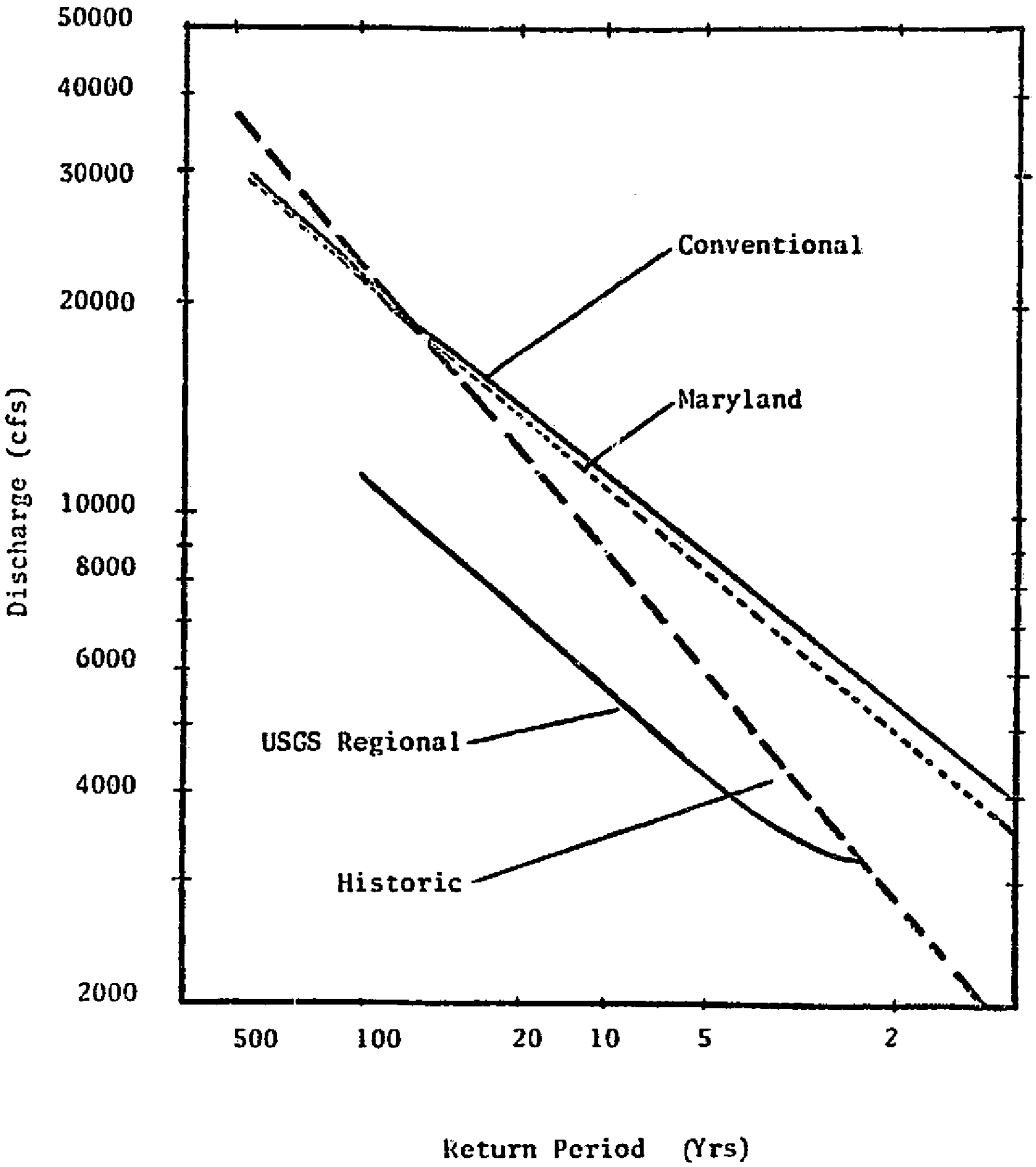

Figure II-10

FOURMILE RUN FLOOD FREQUENCY CURVES

TABLE II-20

Watershed Requirements

INPUT OR PARAMETER	PERMISSIBLE TOLERANCE	RELATIONSHIP TO WATERSHED GEOMORPHOLOGY	DERIVATION FROM REMOTE-SENSED DATA	REQUIRED IMAGE RESOLUTION*
IMPERVIOUS AREA (FIMP)	14% OF FIMP 1.4% OF BASIN AREA	ROCK OUTCROPPING; STREETS, HIGHWAYS, CITIES	IMAGE ANALYSIS: LAND USE CLASSIFICATION	100 M (ERTS, SKYLAB)
WATER SURFACE AREA (FWTR)	15% OF FWTR 1.5% OF BASIN AREA	LAKES; PONDS; RIVERS	IMAGE ANALYSIS: LAND USE CLASSIFICATION	120 M (ERTS, SKYLAB)
VEGETATIVE INTERCEPTION (VINTMR)	+95% -60%	TYPE & DENSITY OF VEGETATIVE COVER	IMAGE DATA CLASSIFICATION & INTERPRETATION	200 M (ERTS, SKYLAB)
MEAN OVERLAND SLOPE (OFSS)	+200% -67%	TOPOGRAPHY: DISTANCES & RELATIVE ELEVATIONS	IMAGE ANALYSIS & MEASUREMENT	100 M HORIZONTAL; 20 M VERTICAL (AIRCRAFT)
MAXIMUM INFILTRATION RATE (BMIR)	+35% -28%	SOIL ASSOCIATION/TYPE	INFER FROM VEGETATIVE COVER; LOCATION & CLIMATE	200 M (POTENTIAL EOS APPLICATION)

*GENERALLY DEPENDS ON AREA OF WATERSHED OR SMALLEST SUBWATERSHED.

Coastal Plain, it is difficult to impossible to develop stream networks using the current Landsat packages.

Landsat is now being used in a number of 208 studies which are developed for determining non-point sources of pollution in urbanized areas. Water resource related land use categories are being delineated (Rogers, et al.; NAΔ) and mapped to a scale of 1:24,000. The cost for this type of study is in the vicinity of $7.40 per square mile.

Thus far, we have been concerned with no more than nine land use categories with respect to water resources. Remote sensing scientists in the area of agriculture have shown that many more land use categories can be developed from Landsat. Those working in urban geography have shown that population distributions and the economic status of the population distributions can be developed from Landsat data (LARS Milwaukee Study). These findings indicate that much more use of Landsat will be coming in the future with respect to water resource related inventory studies as well as the 208 studies.

6. Current Limitations

One of the most widespread criticisms of Landsat multi-spectral scanner data by urban hydrologists is its resolution. The complaint is that the 80 meter resolution is simply not small enough to yield the information required in urban planning studies. This criticism is probably not justified in most of the work with which urban hydrologists are concerned. True, the resolution does not allow the Landsat data to be used for the design of individual catch basins, but when dealing with a watershed of several square miles the resolution provides data within a large number of 1.1 acre cells which quite accurately reflect the averages involved. Table II-21 is presented as an example of the agreement possible between Landsat and 1:4800 photography on a 132-square mile watershed. In this particular case, 10,680 pixels provided an excellent definition of the average distribution of the land uses within the drainage basin. Part of the criticism against the resolution rests in a lack of understanding on the part of many urban hydrologists of the capabilities of computer-aided analysis of Landsat data.

A second limitation in the use of Landsat data is the lack of geometric agreement with map scales and a difficulty in determining the position of a Landsat element on the ground. These criticisms

TABLE II-21

Percent of Watershed Devoted to Specified Land Use

1 Land Use	2 Large Scale Aerial Photo	3 Landsat
Forested Areas	30.7	27.0
Highly Impervious	4.9*	6.5
Grassed Areas	8.5	10.4
Residential	44.9	43.5
Streets and Highways	9.9	5.5
Bare Land	N.C.	.4
Stream	1.0	N.C.
Pond or Pool	.1	N.C.
Unclassified Pixels	--	6.7

N.C. - Not Classified

* Industrial-Commercial-Parking Lot

are justified. Numerous experimenters have been unable to find the boundaries of small watersheds having drainage areas in the vicinity of two or three square miles. If a land mark is available within the watershed or its vicinity then the location is relatively easy. But frequently, such is not the case. Also, this geometric inaccuracy produces a difficulty in interfacing the Landsat data with information obtained from other sources. In urban hydrology there will never be a single platform or single sensor that can provide all the information needed. Therefore, the versatility of any sensing system is highly contingent on its ability to interface with parallel data.

Another problem rests in the confusion of land use classes which result with the current machine-aided classification techniques. For example, the highly impervious suburban shopping centers are very difficult to separate spectrally from bare soil. Older residential areas with shade trees on the lots are difficult to discriminate from totally forested areas. Shadows produced by multi-story buildings in the central city areas frequently result in part of the area being classed as water. The spectral signature produced by two parallel roadways separated by a grass median strip is frequently confused with the residential classification. With effort, these problems can be at least partially corrected with current techniques, but it does increase the time involved in the machine classification.

The use of Landsat multi-spectral scanner data would be increased if the pattern recognition techniques currently programmed could be modified for more versatility with respect to urban problems. For example, classification is on a pixel by pixel basis with each being assigned to some category in accordance with some decision rule. It would probably be better in an urban area to classify groups of pixels into categories as opposed to single pixels. This is different than clustering as we currently know it.

The lack of computer-aided classification equipment is a big limitation in the application of Landsat. If one is in Washington, D.C. he has access to several facilities that can provide him with machine classification services. If he is in Charlotte, N.C. he must travel a considerable distance. Thus, effort is going to have to be

devoted to the development of flexible equipment that can be interfaced with traditional general purpose digital computers. Another factor is the lack of training by individuals concerned with the use of Landsat data.

7. Impact of Landsat Follow-on

a. Improvements in Quality of Data. There are three factors in the proposed Landsat follow-on package that will represent a tremendous improvement in the quality of data for applications in urban hydrology. The improved resolution to 30-meters on the thematic mapper, the inclusion of a thermal band, and the geometric corrections prior to the distribution of the data will have a tremendous impact on the utility of the Landsat products.

The 30-meter resolution will allow some utilization of air photo interpretation techniques of the hard copy products for some of the urban hydrologic tasks. Examination of the Skylab S-190-B photographs which have a resolution of approximately 23 meters gives some indication of the improvements that can be expected with the improved Landsat follow-on resolution. For example, residential areas on a color cathode ray tube display of the Landsat digital tapes generally show as a light pink as opposed to the darker red of a completely grassed area. During some seasons these two categories can be mixed. Based on the experience with the Skylab products, it can be anticipated that the 30-meter resolution will show "linears" created by streets and rows of houses in the residential areas which will make much easier discrimination between it and other classes. It should also be possible to isolate multi-family residential categories away from the single-unit areas, which is important to the task of water quality estimates.

The 30-meter resolution will cause the older residential neighborhoods having foliated loss to have a "mottled" appearance by comparison with a completely wooded area. This will be created by small areas of roof-tops and paved surface showing through the trees, which is not apparent with the 80-meter resolution on the current Landsat. Classification techniques for automatic pattern recognition can be developed to handle this discrimination.

The geometric corrections that will be included in the product will

be extremely important in urban hydrologic problems. The current problems associated with skew and distortion make it extremely difficult to interface Landsat data with other information required in hydrologic studies. By overlaying the Landsat products onto topographic maps, it will be much easier to develop parameter estimates for models and to develop inventory studies. The inability to directly overlay Landsat products with map information has been an important psychological barrier to its widespread utilization.

The inclusion of a thermal band, even though the resolution is in the vicinity of 120 meters, will do a great deal in reducing the confusion between classes. For example, the thermal band should easily discriminate between a shopping center and a large area of bare soil. The same is true with the shadow effect in urban complexes creating a confusion with water in the current Landsat package. It is believed that the thermal capability will be a very important factor in discriminating between natural features and those developed by man.

The short lag times between overflight and availability of data will also be attractive. The nine-day frequency will prohibit routine utilization of the flood and disaster monitoring, but there will be instances where it will be valuable because of its coincidence with a flood event. Even though not directly of use in flood forecasting and flood monitoring, the more rapid availability of the data will make it much more attractive to those hydrologists concerned with urban problems. One area with which urban districts are becoming increasingly concerned is that of sediment, especially during the following construction. Even though the sediment control laws available to many urban governments are very strong, the limited budgets for inspection and monitoring have reduced their impact. The availability of the data on a short turn around basis will be very attractive in locating new construction sites and monitoring the impact of these activities.

b. Improvement of Task Efficiency. The improvement in task efficiency has actually been discussed to a large degree in the preceding section. The availability of a photo interpretation capability should make the Landsat follow-on package much more attractive to a larger group of urban hydrologists. At present, many municipal governments,

and most of the 3,069 counties in the United States, cannot afford to invest the man power or money in automatic pattern recognition techniques. However, they can move toward the photo interpretation capability with a minimal effort and expense. This capability, coupled with the geometric corrections, should make the Landsat package much more readily available to the small organization that will make infrequent use of the products.

c. Auxilliary Data Required. As stated several times before, no single platform will ever be capable of satisfying all the information required in urban hydrologic studies. Even though the Landsat follow-on package will be a tremendous improvement over the current multi-spectral scanner products, census tract data, stream discharges, etc. will still be needed. Still, one cannot place enough emphasis on the fact that the geometric corrections of the Landsat follow-on program will make interfacing with this auxiliary data a much easier task.

8. Research Needs

a. Computer-aided Classification. There will be a continuing need to improve the automatic pattern recognition techniques involving land cover classifications of the digital tapes. As stated before, a pattern recognition program in which the decision rule is based on clusters of pixels rather than single pixels would be an extremely attractive approach in urban water resource studies. Development of programs that are more compatible with general purpose computing machinery is also an important need. Presently, many potential users consider that machine processing capabilities are available at only a few locations. Systems that can be operated by consultants or agencies from the remote terminals that they presently use to access a general purpose computer net would aid in the utility of Landsat data.

More work needs to be done in developing the mechanics of efficient interfacing with auxiliary data needed for water resource studies. The correction of the geometrics will go far in alleviating this problem. Still, the large quantity of data involved and the need for multi-layered random access storage encompasses problems that the routine programmer with a small organization cannot handle. It would probably be a good idea for NASA to develop and distribute the software to accomplish this interfacing function.

b. Model Development. Most of the models used to estimate the quantity or quality of water were developed long before the launching of Landsat. The parameters were designed to be derived from readily available data. Generally this readily available data centers on topographic maps. Much of the data required as input to these existing models simply cannot be defined even with Landsat follow-on. There is nothing sacred about the parameters of these existing models, they were simply derived to use information that was available at the time of model development. There is no reason that alternate parameters cannot be developed that could be identified with Landsat. It is important that extensive research be undertaken to develop such models. Some success with the SCS and STORM models (AGU SCS paper; Ragan,; Jackson,) has been achieved. Still, a well designed research program using a national data base is an important element in the long-term application of the Landsat follow-on program.

c. Organizational Constraints. The numerous municipal and 3069 county governments who administer most of the 12 billion dollar annual expenditure on urban water resources constitute a large potential user of Landsat data. Still, most of these governmental organizations probably spend less than $3,000 per year for their inventory and parameter estimating responsibilities that could be accomplished on Landsat data. Thus, it is not very attractive for them to train personnel, visit browse centers, screen Landsat scenes, and purchase tapes as part of an alternate effort to accomplish their responsiblities. Thus, the establishment of regional, or perhaps state, centers that would routinely classify the land cover within their jurisdictions should be established. In this way, the smaller governmental organizations could simply request information within a watershed boundary, census tract, or other geographic area. The 19 million dollar potential annual saving by shifting from traditional to Landsat cover and parameter estimating approaches cannot be achieved unless there is some attractive mechanism by which the local governments can participate.

TABLE II-22

Requirements Assessment Table

3 = Essential

2 = Very Valuable

1 = Desirable

0 = Inconsequential

	Digital Format	Image Format	Regional Image Coverage = 50 mi/side	Stereo	High Resolution	Visible/Near IR	Thermal Bands	Rapid Cycle	Seasonal Coverage	Rectilinear Presentation
Snow Water Content	3	3	1	0	1	3	3	3	0	1
Snow Covered Area	3	3	1	0	1	3	3	3	0	1
Thermal/Reflectance Characteristics	3	2	2	1	0	3	3	3	0	1
Inland Waters	2	2	1	1	2	2	2	2	2	0
Subsurface Water Supply	3	3	2	2	2	3	2	2	3	1
Water Resource Management	3	0	1	0	2	3	3	3	3	1
Inland Lakes - Water Quality	3	3	2	0	3	3	2	3	3	2
Lake Ice Monitoring	1	2		0	3	2	2	3		
Sediment Requirement Assessment	3	3	3	1	3	3	3	3	3	3
Estuarine Dynamics	3	3		1	3	3	3	1	3	
Inundated Areas and Shorelines	3	3	2	0	3	3	2	2	0	2
Basin Physiography and Land Cover	3	3	2	2	3	3	3	1	3	2
Runoff Modeling	3	3	2	1	2	3	3	1	3	2
Urban Hydrology	3	3	2	2	3	3	3	0	3	3
Inland Waters (General)	3	3	1	0	3	3	2	3	3	2

APPENDIX A

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APPENDIX B

ACRONYMS

AGU	American Geophysical Union
ASG	Applications Survey Group
ASVT	Applications Systems Verification Test
ASVT	Application System Verification and Transfer
CCT	Computer Compatible Tape
COG	Council of Governments
DAM	Detection and Mapping
DCP	Data Collection Platform
DCS	Data Collection System
EPA	Environmental Protection Agency
ERL	Environmental Research Laboratories
EROS	Earth Resources Observation Satellite
ERTS	Earth Resources Technology Satellite
ESMR	Electrically Scanned Microwave Radiometer
FOV	Field of View
GHz	Gigahertz
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
GPO	Government Printing Office
HUD	Housing and Urban Development
IFOV	Instantaneous Field of View
IR	Infrared
JPL	Jet Propulsion Laboratory
L-1	Landsat 1
L-2	Landsat 2
L-C	Landsat C
L-Fo	Landsat follow-on
MARAD	Maritime Administration
MSS	Multi-Spectral Scanner
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service

ppm	parts per million
RBV	Return Beam Vidicon
r. s.	remote sensing
SCS	Soil Conservation Service
SLAR	Side Looking Airborne Radar
SMS	Synchronous Meteorological Satellite
SMSA	Standard Metropolitan Statistical Area
S190A	Skylab Experiment Designations
S190B	Skylab Experiment Designations
STORM	Surface Treatment, Overflow, and Runoff Model
TM	Thematic Mapper
USACE USACofE	U. S. Army Corps of Engineers
USCG	U. S. Coast Guard
USDA	U. S. Department of Agriculture
USDI	U. S. Department of Interior
USGS	U. S. Geological Survey
VHF	Very High Frequency
VHRR	Very High Resolution Radiometer
WMO	World Meteorological Organization

APPENDIX C

RESUMES

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1968-Present	USGS, Washington, D. C.; Reston, Virginia. Administrator and coordinator of the remote sensing program, USGS Water Resources Division. Since 1972, Chief, Office of Remote Sensing, USGS, WRD.
1960-1967	USGS, Fairfax, Virginia. Project Chief, study on the effects of urbanization on flood-peak magnitudes. Developed techniques to delineate flood-hazard areas on Fairfax County streams.
1956-1959	USGS, Washington, D. C. Research study on low-flow frequencies. Runoff from Chamberlin Glacier, northern Alaska. Hydrologic studies on Ellesmere Ice Shelf, N.W.T., Canada.
1952-1956	USGS, Tacoma, Washington. Indirect measurements of flood discharges. Hydraulic studies at bridge sites. Flood studies on small streams (crest stage gage program).
1948-1951	USGS, Tacoma, Washington. Low flow study on Little Spokane River. In charge of USGS snow survey program in western Washington.

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1970-Present	Member of Scientific Planning Panel to develop a scientific package for lunar and Mars roving vehicles.
1969-Present	Member of Viking Molecular Analysis Science Team for remote analysis of Martian soil material by gas chromatography-mass spectrometry and television imagery.
1965-Present	Use of aerial photography in the study of landslides and debris flow activity along the Colville River in northern Alaska.
1950-1953	Use of air photos in mapping portions of the basin and range province in central Utah through the preparation and production of geologic and topographic maps.
1946-1949	Radar guidance and navigation techniques, including radar altimetry, installation, operation and repair of ground control approach radar landing systems.

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Before coming to TAMU, Dr. Blanchard was a hydraulic engineer with the USDA/ARS in Chickasha, Oklahoma. He has been involved in cooperative work with universities, NASA centers, federal and state agencies, and is credited with nearly forty publications and presentations. Presently he is serving on the following NASA committees: Shuttle Imaging Radar Users Working Group, Inland Water Resources Applications Survey Group and in an advisory capacity on the projected hydrology satellite (Hydrosat). His current research projects are directed toward development of sensor capabilities for mapping watershed runoff potential.

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Dr. Boland has been employed for five years in both the public and private sectors of the economy as a remote sensing specialist. His Ph.D. Thesis evaluated the Landsat MSS as a means to classify inland lakes in the United States. He is currently on detail from the University of Nevada to the U.S. Environmental Protection Agency (Las Vegas) where he is continuing to explore the utility of Landsat MSS as a tool in lake monitoring and survey programs.

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1973-Present	Deputy State Engineer, State of Colorado. Responsible for all engineering functions with respect to water resources in Colorado as well as engineer advisor on all interstate compacts.
1971-1973	Chief of Planning, Colorado Division of Water Resources. Responsible for planning the utilization and development of the water resources of Colorado.
1970-1971	Chief Hydrologist for Parker & Associates a private consulting firm specializing in water supply development and distribution systems.
1964-1969	Civil Engineer with U.S. Army Corps of Engineers designing and supervising construction of various airfields, roads and hydraulic structures.

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Formerly Director, Office of Water Research and Technology, Department of the Interior; Technical assistant for water resources, Office of Science and Technology, Executive Office of the President; Director, Water Resources Center, University of California, Research, teaching and administration, University of California (Los Angeles, Davis and Riverside) 1947-1974 in water resources systems engineering.

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Dr. Jones joined Morton W. Bittinger & Associates Inc. at the time of its incorporation in 1970. This firm specializes in land and water resources studies. Dr. Jones is a hydrologist with previous experience in the state governmental, private and university sectors.

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Undergraduate degree (B.S.) in Geology emphasis in hydrogeology. Graduate work in environmental geology at University of Texas at Austin. Course work in engineering geology, advanced hydrogeology, geomorphology, mineral resources. Worked for one year as a research scientist assistant with the Bureau of Economic Geology, Austin, Texas, on the "Environmental Geologic Coastal Atlas Project." Master Science in Community Regional Planning, University of Texas at Austin (1974). He worked as a Natural Resources Planner for the state of Ohio, Department of Natural Resources, on Ohio's Coastal Zone Management Program (1974-1975). He is presently working on the staff to the Great Lakes Basin Commission's Standing Committee on Coastal Zone Management.

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After graduation from VMI, spent two years with Army Corps of Engineers as a hydrologist and officer. Following a year as a designer with the consulting engineering firm of Whitman Requart and Associates, went to graduate school at MIT. Taught since 1959 at the Universities of Vermont and Maryland. Research activities have concentrated on hydrologic processes and remote sensing.

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1967-1972 - Hydrologic Engineer in Hydrologic Branch, Tulsa District, Corps of Engineers, involved in survey studies, design memos, and hydrologic investigations for multi-purpose water management projects.
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1974-present - Hydrologic Engineer in Water Control Center, North Central Division, Corps of Engineers, involved in International Joint Commission activities in the regulation of the Great Lakes and connecting rivers. Involved in developing an inter-agency hydromet system to monitor and forecast Great Lakes conditions. Assist in managing hydrologic studies and review of reports.

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14 years with the U. S. Geological Survey in Washington, D. C., Arizona, and Boston, Massachusetts. Survey's first Geohydrologic Map Editor. Research Hydrologist with Navoceano's Coastal Oceanography Branch, 1967-1971, with thermal infrared surveys of coastal areas undertaken in Vietnam, Republic of Korea, and Piscataquis River, Maine. Senior Research Hydrologist, NOAA/NESS, 1971-present. Responsible for planning and implementing program to develop satellite applications in the field of hydrology.

PART 4

LAND INVENTORY

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CHAPTER I

OVERVIEW AND RECOMMENDATIONS

The purpose of this report is to present an evaluation of the proposed Landsat follow-on program relative to its impact on the following land use-related applications:

A. Natural Resource Inventory
B. Forestry, Range and Wildlife
C. Wetland Mapping and Inventory
D. Coastal Zone and Shoreline Mapping
E. Mapping and Cartography
F. Surface Mining Extent and Reclamation
G. Urban and Special Environments
H. Information and Management Systems

The evaluation was developed in terms of accomplishments that can be achieved with conventional data, existing Landsat data, and the proposed Landsat follow-on.

The chapters of the report are basically structured in order of increasing detail. This chapter presents a brief overview which identifies major areas of user problems and opportunities with conclusions and recommendations of the Land Inventory Sub-Group. Chapter II includes detailed reports submitted for applications A through H above with technical considerations explained in more detail.

Land Inventory requirements have increased dramatically over the past ten years. Many problems, such as the U.S. Coastal Zone Management Act, the National Environmental Protection Act, the Army Corps of Engineers' 404 Permitting Program, the 208 element of the Federal Water Pollution Control Act Amendments, and others have elements which are still developing and therefore do not yet have specific, fully-defined requirements for data. Many programs and activities also have long term objectives for which data requirements or criteria mav change over time. For these reasons and others to be discussed, there are at present few operational uses of Landsat data in the United States. However, there is a wide variety of potential land inventory-related applications of existing and proposed Landsat data, a number of techniques for which have been tested and indicate a significant future usefulness.

In terms of the data requirements for each application, there are several areas of overlap -- areas where more than one application can benefit from the same data and/or criteria. There are also areas which are mutually exclusive; criteria for one application may preclude successful results from another, thus requiring a trade-off. The following section will give a brief overview of these factors and recommendations as they relate to the Landsat and Landsat follow-on programs. Chapter II itemizes these factors by application.

The most frequent suggestions from the applications sub-groups involve an OPERATIONAL PROGRAM and QUICK TURN AROUND time.

* for existing and proposed Landsat data to be used in an ongoing way and to achieve a satisfactory user confidence level requires an OPERATIONAL commitment rather than experimental program.

* current turn-around time is unacceptable -- the program must provide a much SHORTER DELAY PERIOD on a consistent basis if data is to be used regularly.

Technical changes in the Landsat follow-on satellite's criteria are a major consideration:

* increased bands and resolution of Thematic Mapper will probably enhance nearly all applications identified and produce better results.

* changes in geometry (altitude, time of equatorial crossing, sun angle, etc.) may cause problems such as compatibility with existing data, increased cloud cover and sun glint. Proposed geometry should be investigated relative to existing geometry to determine the extent of problems which may arise in terms of non-compatibility.

* continuing the nine-day coverage is preferred. If the coverage is 18 days there is less chance that adequate cloud-free data will be available when desired for many regions in the country.

Several different sources of data are required to meet the needs of most programs; therefore:

* Landsat data should not be viewed as a stand-alone program. Photography is the most common form of support data required. The federal government has continued responsibility for producing aircraft photography for mandated programs. This should be done as a cooperative effort involving the federal/state governments, and private firms with aircraft remote sensing capabilities.

* it should be recognized that in some cases Landsat data may not be acceptable for an application, even with improved characteristics and operational status.

The majority of potential users need meaningful data that can be used in an efficient way, therefore:

* Landsat data should be geometrically rectified and registered before distribution.

* archiving of raw data is desired, especially for cartographic applications.

* coordination among data users and providers needs to be improved.

* the use of digital processing techniques is expected to increase, as opposed to imagery interpretation.

A common concern is that specific needs for specific applications be considered in the decision of future data collection activities. Therefore:

* potential users should continue to have a more direct input in development, defining criteria, specifications, formats, etc., of future data products. Proper design of Landsat follow-on will add important applications, specifically those requiring water penetration, better resolution, increased gray scales.

* potential users should have more exposure to the basic training period.

* better access to browse files is needed.

CHAPTER II

APPLICATIONS

A. INTRODUCTION

Individually, the applications evaluations of Landsat are found in this chapter. Within the applications sub-group there is a general consensus that for Land Inventory Related Applications, the Landsat program is a valuable tool which will assist in completing specific management-oriented tasks in an efficient and dynamic manner, and to this end, the Landsat follow-on programs should be supported.

The following is a brief summary by application sub-group of tasks that are of interest using Landsat data:

1. Natural Resources Inventory

Specific requirements for this application deal with

* water quality planning - PL92-500
* comprehensive planning - HUD 701
* watershed planning - SCS PL89-566
* environmental impact studies - NEPA (PL91-190)
* Coastal Zone Management Act of 1972

These change detection capabilities and documenting or updating maps showing areas of generalized land cover (croplands, open space, urban areas, water, etc.) are of further need for mandated programs.

2. Forestry, Range and Wildlife

This application would involve improving accuracies and efficiency of forest volume inventory through multi-stage sampling, monitoring changes, such as those caused by fire, hurricanes, tornadoes, disease, insects, etc., delineating areas of clearcutting, conversion, regeneration, etc., discrimination areas of soil deficiency, underlying geologic and soil characteristics, etc.

3. Wetland Mapping and Inventory

This application could relate to regulation of dredge and fill operations (Army Corps of Engineers/NEPA), as well as the U.S. Fish and Wildlife Services' National Wetlands Inventory. Potential applications exist for inland wetlands inventory, species composition related to salinity and primary productivity location of mosquito breeding habitats, wildlife habitat diversity, and identification of man-made structure and soil disposal sites.

4. Coastal Zone and Shoreline Mapping

Landsat data could be used for the following:

* mapping of significant shoal features
* surface circulation and water currents
* measuring large features such as shoreline changes
* hydrographic charting of reefs, islands, etc.

A substantial savings could result from using Landsat data to pre-survey and chart vast areas of ocean. Other properties of coastal water which have been observed and measured are sub-surface topographic and bathymetric features, location and measurement of pollutant, areas of high bioproductivity using color indications of chlorophyll concentration, and depth determination. There is evidence that quantitative sediment processes may be mappable for Landsat. Significant cost savings could result from using Landsat to measure storm-induced shoreline changes in shape, dimension and location; conventional techniques are time consuming, expensive and limited in areal scope.

5. Mapping and Cartography

This application would involve:

* small scale planimetric mapping and revision to 1:250,000 scale
* recording land features and land-water interfaces
* hydrographic charting and planning hydrographic surveys
* automated production of small-scale cartographic products

Thermal and water-penetration bands will enhance thematic and shallow sea mapping tasks. Seasonal mapping is possible. Automated (autographic) theme extraction has been applied to water, vegetation and snow; and numerous thematic maps using manual and automated means are being produced by various state and federal agencies.

6. Surface Mining Extent and Reclamation

Landsat activities may include:

* surface land cover classification
* change monitoring of strip mined areas
* monitoring progress of reclaimed areas

Of further interest is detection, identification, and mapping of the secondary effects of surface mining such as erosion, subsidence, vegetative stress, and sedimentation. Usefulness is indicated for annual updating of information.

7. Urban and Special Environments

This application would involve:

* general cover categories at the metropolitan level
* change detection for preliminary surveys prior to specific aircraft flights or field investigation

Most urban areas have inventories beyond Landsat capabilities. Change detection can help make updates more efficient. Some urban studies using Landsat data include documenting land use change by census tract, interfacing Landsat with census urban atlas file (tract boundaries), and urban boundary delineations.

B. NATURAL RESOURCE INVENTORY

Systematic methods for collecting, recording, and interpreting data related to natural resource conditions are increasingly needed to gain a better understanding of natural conditions for making, planning, development, or management of various federal and state programs. This need for natural resource inventories should be designed to allow follow-up monitoring so that changes in conditions can easily be documented.

1. Laws and Other Demand Factors

An expanded concern for the environment and careful planning for the wise use of our natural resources have resulted in both public and private agencies to face the need to provide intensive planning and management programs which meet the requirements of new state and federal laws. These laws require the establishment of baseline data accurately portraying natural conditions and allowing monitoring systems to easily identify change.

Examples of laws and programs which support the need for expanded natural resource inventories and/or regional land-use inventory systems follow.

(a) P.L. 92-500. Section 303e of the Federal Water Pollution Control Act requires water quality plans to be developed for all the river basins in the United States. This planning process requires a careful analysis of the interrelationships between properties and how these relationships affect water quality. Provisions are also to be made for regular monitoring and updating of data. Several federal agencies, state environmental protection agencies, and water pollution control boards, and regional planning agencies are involved in this program.

(b) The Department of Housing and Urban Development now requires comprehensive areawide land-use plans to be completed by August 1977 for all agencies utilizing HUD's 701 Planning Assistance funds.

(c) The Federal Water Pollution Act of 1972, Section 208, requires that state and local jurisdictions provide plans which show how the state will deal with point and non-point pollution sources. In developing such plans, the relationships between waste disposal, water conditions, land use, and natural characteristics must be carefully analyzed.

(d) The Federal Water Pollution Control Act of 1972, Section 404 require the Army Corps of Engineers to be responsible for granting permits for dredging, soil disposal or filling activities within waterways, wetlands and shoreline areas. To be successful, this program will require periodic monitoring of conditions for enforcement -- possibly on a week-by-week basis.

(e) The Soil Conservation Service, under laws 74-46 and 89-560, has been publishing soil surveys of various counties. The data collected is to be utilized in decision-making processes involving land-use as well as agricultural practices. In addition to this, the Soil Conservation Service has made inventories to assist in identifying areas of water impoundments, recreational developments, etc.

(f) The Bureau of Outdoor Recreation, under the Land and Water Conservation Fund, provides support for outdoor recreational systems. The county and/or state agency applying for funding, however, is required to develop comprehensive areawide plans for the development of such recreational projects.

This includes an analysis of natural features.

(g) In metropolitan areas, planning grants are given for the development of area-wide transportation systems. These planning grants also require intensive collection of data on land use, population characteristics, and natural features.

(h) The National Environmental Policy Act (NEPA) required as part of various federal and state programs that extensive environmental impact statements be prepared before construction of projects such as highways, electric generation plants, transmission corridors, airports, parks, and other major public works endeavors. These environmental impact studies require very careful analysis of the potential effects of proposed projects on natural conditions. Again, there is a need to determine the capabilities and constraints of the landscape. This requires an intensive study of the natural resources within the area of concern.

(i) Other programs that require monitoring of natural resource or land-use systems are coastal zone planning, regulation of strip mining, siting of nuclear power plants, and numerous other activities of state and federal agencies.

In addition to laws and federal programs which mandate the development of land use and natural resource inventories of various types, there are many state agencies and some federal programs which involve land use data systems.

(a) The United States Geological Survey has implemented a land-use, inventory (LUDA) mapping program. The map products produced in this program will provide valuable land-use data to various state agencies. The cost of this mapping is on a cost-sharing basis.

(b) Although a national land-use bill has not been passed, many states have enacted their own land-use bills requiring either local or state agencies to make inventories of land-use conditions in accordance with pre-described procedures. These inventories generally involve the identification of sensitive natural conditions and require a careful analysis of environmental inter-relationships.

Most of this natural resource inventory data is presently collected either through traditional air photointerpretation techniques or specific site investigations. There has been, however, very little coordination of the data collection or planning between various agencies. Literally millions of dollars have been spent in almost every state to collect, interpret, and display similar natural resource or land-use data for different types of studies. It is not unusual, even on a county level, to find transportation, recreation, water quality, soil survey, and land-use data available for a specific area; but these sources often utilize different scales or descriptive terminology and levels of accuracy. This situation results in data sources which are neither comparable nor compatible and therefore are difficult and expensive to use for comprehensive planning purposes. This points to an imperative need for the integration of natural resource and land-use inventories so that methods of collecting, interpreting, and presenting data may be standardized. What is now occurring is that Landsat is beginning to eliminate inconsistent and sometimes contradictory planning policies that result from the segmental type of data collection and interpretation presently occurring in many federal, state, and local programs.

The Landsat imagery and data system currently being developed should be promoted as one very powerful tool in meeting the growing needs for natural resource and land-use planning/management needs of the nation. Landsat should not be viewed as the total answer for all data collection and inventory needs because the collection and the analysis of some needed information (detail, soil, hydrologic and geologic information) is currently beyond the capacity of existing Landsat systems.

Landsat imagery and systems can fill a very important role as a COMMON DENOMINATOR around which other data systems can be developed. Presently, Landsat systems can be used with a high degree of confidence in performing simple functions related to the description, mapping, and analysis of data relating to general land cover.

Landsat being used for this function will provide the synoptic, repeatable view of general conditions needed to provide coordination in what now exists as inconsistent current planning effort.

The initial cost of providing the programs, software, and hardware to develop Landsat imagery data is apt to be higher than traditional data collection and interpretation systems (air photointerpretation with ground checks); however, as updates are needed Landsat applications become progressivley cheaper and provide more information than the traditional approaches. The long run cost of developing a Landsat program therefore will be far cheaper than traditional approaches.

Furthermore, as Landsat systems become more operational and further system improvements are made, expanded applications of Landsat imagery can be expected.

2. Examples of Landsat Program Contributions

The Landsat program has been responsible for the development of many technical applications which can meet all or part of the land-use or natural resource inventory needs listed above. For example, the State of Arizona, working with the U.S. Geological Survey, has developed a Landsat image mosaic covering the entire state. The Arizona Satellite Image Map has been published at a 1:500,000 scale by the U.S. Geological Survey, and is available as a black and white image base and as a sepia-tone image base with highways, place names, major drainage, and other cultural information overprinted on the sepia-tone base. The resulting map is easily used by non-technical persons to grasp the physical and cultural relationships of Arizona.

The State of Arizona has used the image map as a base for a series of overprinted thematic maps at a scale of 1:1,000,000. The image base provides the realism important in communicating the Statewide geographic distribution of information. These image base maps serve as working bases for the development of special map products such as wildlife habitat maps, for direct snow mapping from small aircraft, and for mapping conditions visible on subsequent Landsat imagery. Conversely, an interpreter of Landsat imagery can utilize the thematic overprinted maps to aid in interpretations; i.e., the image base map with climatological information including weather stations enables the interpreter to relate climate conditions and specific weather data to areas on the Landsat scene.

The spatial resolution of Landsat data is not apparent on the image maps and the detail of Landsat follow-on most certainly will not be directly relatable. It is important to note, however, that the standdard scale image maps provide an excellent, easily comprehended base upon which to display and communicate the results of detailed Landsat analysis. The Arizona Satellite Image Maps are communicating, at a standard scale, the advantages of common scale maps for displaying and transferring information.

The Multiple Input Land-Use System (MILUS) which has been developed by the Jet Propulsion Laboratory utilized Landsat data to prepare a base so land-use inventories can be generated. Other spatially referenced data may also be incorporated into the MILUS system to provide a comprehensive management base information system. MILUS has been successfully demonstrated in Los Angeles and Orange Counties, California, and also in St. Tammany Parish, Louisiana. Local governmental agencies in these areas have found the MILUS information useful and relatively inexpensive.

The State of Georgia has been exploring the possibility of utilizing Landsat imagery to establish a management planning system for non-point source pollution as part of Section 208 of P.L. 92-500.

Landsat data will be used to develop a basic inventory related to:

1. high density urban (high percentage impervious cover);
2. low density urban (low percentage impervious cover);
3. base ground - exposed soil, exposed rock, spoil, sand (beach or spoil);
4. agriculture production lands - row crops;
5. pasture or grasslands;
6. forested areas - deciduous, coniferous, mixed;
7. production forests "planted";
8. salt-water marshes, fresh water marshes, sloughs, river swamps;
9. surface water - ponds, lakes, rivers.

Such output should enable the State of Georgia to comply with Federal law by providing data necessary to conduct an effective 208 non-point source program in a scientific, objective manner. Further, the iterative capabilities allow it to be kept updated on a regular basis.

In Iowa a Landsat demonstration study (NAS 5-20832) has shown that computer enhanced images can provide useful planning data from conventional photointerpretation techniques.

The advantage of utilizing satellite imagery is that planners can make rapid assessment of land-cover features without extensive photointerpretation training.

In the Washington, D. C. area, land-use maps were produced from high altitude color-infrared aircraft photography. Updated versions of these maps have been produced by overlaying Landsat computer classified scenes over the original land-use map. This method of comparing data semi-automatically documented changes which have taken place in Washington, D. C. at a significantly lower cost (document by Jim Wray, in preparation).

3. <u>The Landsat Program--Experimental Versus Operational</u>

Most of the present applications of the Landsat systems in natural resource inventory and regional land-use planning have been undertaken by the federal government and state agencies. One of the major problems hindering the increased utilization of satellite data by private or local agencies is the limited life expectancy of the satellite (the design life being three years or less).

Until the earth resources satellite programs are established by the federal government as on-going programs, their utilization by local or private organizations may be constrained regardless of advances in interpretation, processing, or delivery of imagery. As long as the systems are viewed as experimental rather than operational, state and private agencies will hesitate to invest in the development of necessary planning model techniques, staff, and backup equipment needed to make full use of the potentials of NASA satellite information systems.

Considering that the Landsat systems could be made operational by insuring a reasonable period of available funding (10 to 20 years), the following advantages of Landsat data could revolutionize development of natural resource inventories and regional land-use data systems:

1. The Landsat information system creates a uniform data base covering all surfaces of the earth.

2. The Landsat system allows monitoring and updating of data on a nine-day basis. (weather permitting).

3. The synoptic view which Landsat imagery provides allows the assessment of natural resource interrelationships on a scale that cannot be duplicated by other imaging systems.

4. The digital format of Landsat data lends itself to computer classification. Machine processing ensures that the interpretations are

a. repeatable;

b. inexpensive (or at least will be);

c. unbiased;

d. quantifiable;

e. easily acquired for a relatively low investment.

5. Landsat imagery can also be utilized by conventional photointerpretation techniques.

Perhaps the greatest advantage of Landsat data is that it provides a common base on which characteristics of the earth's surface can be compared to other spatially referenced data (for example, soils, geologic, agriculture data). Landsat would seem to be the ideal system for intergrating land-use planning or natural resource inventory data.

To utilize the digital Landsat information, any agency having access to a computer center can acquire the necessary software and hardware systems for as low as $100,000 to do their own image processing. When one considers that many state governments have spent millions of dollars a year on various types of general land use and natural resource inventions, this investment seems to be fairly low for a system that would remove duplications and inconsistencies between what now seems to be competing planning and mangement systems.

4. <u>Limitations of the Present Landsat Program</u>

Limitations to the present Landsat program are listed below.

1. For planning purposes the 80 meter square pixel resolution will not allow certain types of land-cover interpretations to be reliably developed. Subtle changes in features such as shorelines, forest cover, development patterns, etc. are not readily discernible.

2. The experimental mode of the Landsat system is viewed as detrimental to its increased acceptance.

e. Delivery time of Landsat data is judged to be inadequate.

5. <u>Landsat follow-on Program</u>

The Landsat follow-on satellite will possess several improvements which will make it more useful and reliable. These improvements are listed below.

1. Landsat follow-on will have increased resolution (30 meters square) and greater spectral sensitivity.

2. The continued nine-day coverage will allow detailed, sequential monitoring capabilities.

3. Faster delivery time of data will increase the utility of Landsat follow-on.

6. <u>Questioned Design Parameters for Landsat follow-on</u>

It is obvious that certain trade-offs are involved in altering the Landsat follow-on from those design parameters of Landsat 1, 2, or C. Assessments must be made to determine the specific benefits that will be derived from the expanded Landsat follow-on capabilities with the increased cost. Listed below are statements which must be addressed before Landsat follow-on designs are finalized.

(a) Landsat follow-on data may not be comparable to Landsat 1 or C. If it is not, what will be the cost to make the data comparable?

(b) The lower satellite altitude and increased scan angle may degrade the uniformity across the scene to the extent that extensive and expensive corrections will be needed in order to make accurate interpretation of imagery.

(c) The time of equatorial crossing may well cause a decrease of shadows to the point that it will make interpretations of topographical features difficult.

(d) A later time of equatorial crossing may also result in cloud cover problems caused by convectional phenomena associated with near-noon local weather conditions. This will in turn interfere with systematic monitoring of some parts of the world.

(e) A later time of equatorial crossing will increase the area of hot spots in desert and water bodies that will inhibit the use of Landsat follow-on data interpretations in these areas.

7. <u>Summary</u>

The Landsat program has the potential of making major changes in natural resource and land-cover inventories in the United States. The determining factor for the success of this NASA satellite program will depend upon the receptiveness of federal, state, and industrial agencies to use Landsat information systems as a mechanism to order data.

This acceptance will be greater if there is an operational mode to the program rather than experimental.

The expanded capabilities of Landsat follow-on will most certainly enhance the utilization of satellite information. The design parameters of the satellite must be weighed carefully to insure the maximum utility of Landsat follow-on in an operational mode.

The present Landsat systems seem very adequate to provide basic maps and data documenting generalized land cover (croplands, open space, urban areas, water, etc.). In terms of interpreting land cover to determine actual uses of land, Landsat information must be related to ground truth information such as aerial photography entry maps, reports on actual ground checks, etc. The planned improvement of 30 m cell size should expand the reliability of direct interpretation. Actual interpretation of natural properties and conditions such as geologic features, water quality and soil types will be greatly enhanced with planned Landsat follow-on improvements, notably the 30 m cell size, use of the Blue Band and Thermal Bands. For monitoring purposes existing Landsat systems have broad applications which can be made operational with the present state-of-the-art. Improvements in resolutions, however, will greatly expand applications and confidence levels.

Of all the factors influencing use of Landsat those relating to decisions by NASA officials and Congress to make Landsat a long-term operational program will give state and local agencies confidence in utilization of the systems.

TABLE II-1
APPLICATION ASSESSMENT TABLE

Application:

Natural Resources Inventory

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Landcover		
Description of what is there, i.e., man-made features, water, vegetation, crops, barren, wetlands, snow.	Registration: 1-4 acres; unit size: 10-40 acres; frequency: seasonally; format: use standard scales.	Proven.	Ready for operational status.
	Land-Use (Interpretation)		
Land-cover plus ancillary data.	Registration: 1-4 acres; unit size: 10-40 acres; frequency: seasonally; format: use standard scales.	Dependent upon ancillary information.	
	Natural Properties		
Data for management model.		Proven for specific limited.	Requires further research. Natural properties presence or absence of: water, mineral indicators, topography, crop stress, soil moisture, vegetation vigor, etc.
	Monitoring		
Sequential comparisons of data.	Seasonal frequency machine processable geographic registration 48-hour data available.	Change detection feasible but requires refinement.	Monitoring is the most effective long-term effect of Landsat.

C. FORESTRY, RANGE AND WILDLIFE

1. Introduction

In surveying forestry, range and wildlife applications of remotely sensed satellite acquired data, the basic objectives sought by the system must be identified. The current methods now being used along with other developed technology must be evaluated as to their capabilities in reaching the stated objectives. Once the state of the existing art of data collection is established, the question becomes: How can recent developments in remote sensing technology be brought to bear in more efficiently or precisely achieving the goals of the desired system? In such an evaluation, all three parts of the data collection activity must be discussed.

2. Goals and Objectives

Goals and objectives of data collection activity vary widely with user requirements. This is especially true in considering forestry, range and wildlife activity with public and private resource management philosophy and the myriads of specific goals within each major sector. In coping with such a diverse range of needs, the specific direction of range and forestry investigations will endeavor to develop and demonstrate the technological capability to identify range and forest resources, stratify according to vegetation type or species and perform inventories and production estimates for the following purposes:

1. Range Biology and Ecological Management
   - Species and Type Identification
   - Erosion Inventory
2. Forage Production Management
   - Range Condition
   - Forage Volume and Distribution
   - Wildlife Habitat Interference
3. Range Grazing Management
   - Range Readiness
   - Carrying Capacity
   - Forage Depletion
   - Animal Distribution

4. Timber Production Management

   . Production Class
   . Stand Type and Age
   . Timber Size
   . Vigor
   . In-place Volume
   . Seedling Survival

5. Timber Sales Management

   . Precision In-place Volume
   . Stand Type
   . Stand Condition
   . Logging Location/Timing Compliance

6. Recreation Site Inventory and Management

   . Vegetation Cover
   . Water Supply Aesthetics
   . Maintenance Needs
   . Pollution Detection

7. Wildlife Habitat Management

   . Vegetative Density
   . Overstory/Midstory/Understory Species
   . Composition
   . Water Location

Means to Achieve the Goals

To meet the above task, the use of both satellite and aircraft platforms is proposed. In addition, supportive ground data collection will be necessary to achieve the final levels of precision in many cases. Traditionally, managers of forest, range and wildlife resources have relied on aircraft and ground crews as major sources of data. Looking toward the Landsat system and other newly developed remote sensing techniques as a supplement to ongoing methodology, management has been motivated by three basic considerations:

- The need for the data -- the essential need for a quantitative and qualitative definition of the basic resources under management, for current decisions and to establish the future profile of the land and vegetation as may be shaped by these decisions. Such an information base provides a monitor of resource conditions that are vital if reasonable compromises are to be reached while still achieving the productive goals required for the future.
- Timeliness of the data -- to be effective, management decisions must be made as a response to a set of planned alternatives, rather than an after-the-fact reaction generated by a set of circumstances already a foregone conclusion.
- Acquisition of the data -- the ability to acquire the required data within the time frame necessary for management decisions.
- Given the increase in scope of data requirements and the time frame allowed, it is seriously questioned whether traditional data collection methods can keep pace with the data processing and analysis procedures of the future. To meet these projected requirements, methods and techniques must be developed to augment the data acquisition activity without sacrificing the accuracy or precision of the data collected.

3. <u>State-of-the Art</u>

The state-of-the-art, with regard to utilizing satellite-acquired data as a viable information source, involves developed technology from Landsat 1 and 2. Although very few, if any, projects have been developed in an operational atmosphere, that is to say, implementable by a user on a day-to-day basis, results strongly suggest a significant contribution by Landsat to overall forest, range and wildlife resource data systems. Virtually all the applications for utilizing Landsat data in these activities have involved stratification in one form or another. By measuring strata variation through multi-temporal overlays, a method for detecting and monitoring change has been established.

Stratification has been demonstrated in terms of broad vegetative and density categories; i.e., to a level II or III precision (Anderson, et al). Areas of cultural activity have also been delineated, including

clearcutting, conversion to other uses, regeneration, site preparation and improvement. Evaluation of forest stress and damage caused by insects, disease, fire, wind, etc. has also been done.

In forestry, range and wildlife management applications, capability has been demonstrated to broadly stratify land areas into various vegetative cover types.

The highest success in stratification has been at level I, discrimination of forest and range from other land use; i.e., urban, agriculture, barren land, water, etc. Consistently, performance levels of 95 percent and greater have been demonstrated. Hoffer, et al, (1974) indicated in mountainous terrain in Colorado classification accuracies for conifers, deciduous, agriculture, water and bare ground have reached an overall performance record of 94.8 percent, utilizing a modified clustering algorithm. Conifer and deciduous performance was recorded at 95.7 and 85.4 percent, respectively. While these accuracies will vary from location to location, it seems that repeatable performances can be expected from 75 to 95 percent.

Sub-stratifying these groups into a total of eight classes rather than five reduced the overall performance to 76.5 percent. For individual tree species groups, performance of correct classifications were: pine, 81.4 percent; spruce fir, 64.9 percent; oak, 61.7 percent; and aspen, 78.4 percent. For this level III classification, a rapid deterioration of accuracy performance is noted. Evidence indicates that through multi-temporal overlays, classification capability may materially improve. Table II-2 is a partial recapitulation of data presented by Joyce (1974), and indicates significant variation with seasonal coverage. Note the significant decrease in classification capability in January for grass and marshlands, whereas in forested land, the August data seem to provide poorer classification results. These three general areas of classification are important in forest, range and wildlife investigations. It would seem that a multi-temporal composite would highlight the classes of interest. Such a procedure would also make maximum use of the dynamic range of the data.

TABLE II-2 CLASSIFICATIONS WITHIN TRAINING SAMPLE AREAS EXPRESSED AS PERCENTAGE OF TOTAL CELLS REPRESENTING A GIVEN SURFACE FEATURE CLASSIFIED AS PERTAINING TO THAT SURFACE FEATURE.

SURFACE FEATURES (LAND USE)	AUG. 1972 DATA	JAN. 1973 DATA	MAY 1973 DATA
ALL FORESTED	92.4	97.8	96.9
PINE FOREST	81.4	91.5	98.8
SWAMP FOREST	72.7	88.5	95.7
GRASS (IMPROVED AND UNIMPROVED PASTURE)	89.0	80.4	92.5
MARSH (NON-FORESTED WETLANDS)	94.9	67.4	97.0

Vegas (1973) states with reference to sequential imagery from Landsat that: "Sequential imagery is extremely useful, particularly of opposite seasons, and will significantly improve the overall obtainable accuracy by as much as twelve to eighteen percent." He further states that in "...utilizing ERTS for agriculture and forestry purposes, Level II categories are often as easy to obtain as the Level I, particularly when sequential imagery is available." Indeed, referring to Table 1, pine forest (Level II) shows better percentage classification than all forests in the May data. These broad forest classifications were further substantiated in southern Louisiana and Mississippi by Whitley (1973), who shows roughly 85 percent classification performance in conifers and 87 percent in hardwoods, utilizing a supervised classification algorithm on single coverage.

The results reported above compare favorably with other work done in Washington, Oregon, Indiana and several other domestic and foreign locations. Such widespread correspondence seems to indicate that the possibility of repeatability is good, even to a level II precision, and that Level III is sometimes possible.

4. Density Classification (Volume)

Much like forest type mapping, forest density classification is basically a stratification procedure. Through density classifications

gross volume estimates can be made with the best results occurring in the heaviest or dense areas. Raytheon Company (1975) indicates high correlation between forest and dense forest lands as against lower correlations between medium and sparsely stocked stands to Landsat data. The overall forest land correlation coefficient showed .93; heavy forest, .97; medium forest, .73;and sparse forest, only .59. Such a rapid deterioration in the sparse areas indicates confusion with other materials, and substantiates the problem shown in vegetative mapping from Landsat at a Level III. In the cited study, it was pointed out that forest density levels reflected forest stand distribution rather than trees within the stand. Any maps generated from such data form an excellent basis for designing an "...areawide, valid, forest volume assessment."

While broad general density groupings have value, the most important use of Landsat data in this regard is in conjunction with ancillary data in providing a stepwise volume inventory. These multi-stage designs will be discussed later in this report.

Density measurement capability, as related to production, has been reported by Seevers, et al (1975). Here, vegetative giomass estimates were made, which proved useful in managing 20,000 square miles of range land in Nebraska. In this case, the highest density correlations were achieved utilizing CCTs rather than through interpretive techniques using transparencies. With correlation coefficients of .90, Landsat data are reported as valuable aids in grazing management. The one drawback to having an operational system is the slowness of data turnaround.

Other density stratifications which indicate the vigor or health of forest stands have been suggested. Landgrebe, et al (1972), has indicated vegetation, having been subjected to herbicide spraying, but not fatally, leafed out in the spring, showing no visible difference by eye or photograph from the surrounding areas. Landsat imagery indicated a definite reduction in reflectance in channel 7 (near infra-red). This observation indicates Landsat is capable of detecting stress or other differences not obvious by the eye or camera (visible range). Utilizing repeat coverage as a change detection monitor, this seems to be a great potential from the Landsat system. This capability also

suggests the strong possibility of early warning in areas of disease and insect infestation. Evidence indicates the possibility for discriminating areas of soil deficiency. In the same publication as cited above, Landgrebe, et al, suggest that vegetation accurately portrays the underlying geologic and soil characteristics on which it is growing. This also suggests the possibility of broad vegetative associations serving as production indicators.

5. Geometric Registration

Geometric registration is the capability to locate given ground points on remotely sensed images and to accurately superimpose these points from repeated coverage. Without this ability, remote sensing analysis techniques become an academic exercise. Most forestry and range land holding patterns are non-contiguous in nature with land being intermingled with other owners. Within a given ownership, sub-compartmentation in terms of vegetative type boundaries, and operational activity boundaries, presents problems of both regular and irregular delineation to properly document the scene.

Mroczynski, et al (1975), have demonstrated an ability to map out forest types in Indiana to a finer level than in the traditional ground methods. Areas of five acres were mapped through ADP and a Cal-Comp plotter. The accuracy of the classification may well be subject to questions on this small an area, but it does indicate the sophistication of geometric registration which placed boundary location to within a resolution element, 80 meters (270 feet or so).

6. Multi-Stage Sampling

Multi-stage sampling is used here to describe the myriads of multi-stage, multi-phase or multi-tiered sampling designs that are being considered as viable adjuncts to satellite-acquired data. To establish the levels of precision NASA requires, and to be of real use to most users, satellite data must be interfaced with higher resolution, and more precise photographic data sources. These data sources are in turn augmented by lower altitude, increasingly precise data until, ultimately, ground sampling is employed.

The value of Landsat as a first stage contributor to multi-stage

sampling procedures was indicated by Aldrich (1971). Utilizing Apollo 9 data as a first stage of a multi-stage scheme, gross total volume in Mississippi was estimated at some 2.2 billion cubic feet with a sampling error of 13 percent. Only 10 ground plots were used. It was estimated, using random sampling procedures and not stratifying, the sampling error would have been 30.7 percent. Using space photography, in this case to stratify, a 58 percent reduction in sampling error was achieved.

Gialdini, et al (1975), demonstrated a multi-stage forest inventory in which the results reported had a relative standard error of 8.0 percent at .80 probability. In this case Landsat was used to stratify the sample. This efficiency was reflected by a reduced sample variance which would have been obtained using random sampling techniques.

7. The Present and Potential Use of Landsat Data in the Management of Range Resources

The present operational use of Landsat imagery with rangeland resource management has been virtually non-existent except for research applications. Current information on changes in rangeland use is required for proper management of these lands. The system must be able to survey, map, and monitor conditions that cause deterioration of rangeland use capability and soil productivity, and have the capability of being updated frequently.

Potential uses and frequency of analysis of satellite data in range management are outlined:

Types of Application	Frequency of Analysis
1. Vegetative mapping	2 - 5 years
2. Diversified use of rangelands	Annually
3. Identification and monitoring range improvement practices	Monthly
4. Estimation of forage production	Monthly
5. Evaluation or range condition trends	Semi-annually
6. Identification and monitoring of major encroachments of undesirable vegetative species	Monthly
7. Prediction of fire-danger rating	Daily

In most all application systems developed, three problems have been identified with the present satellite imagery usage.

1. Definition of images is not sufficient for field application.

2. Images have not been received in a timely manner.

3. Quality of images are below necessary for field work.

The Landsat follow-on mission proposed for 1980-81 as identified should alleviate these problems identified with rangeland usages. The main characteristic of an improved ground resolution to 30 meters from 79 meters will benefit range resource management the greatest. The predicted shorter turn-around will also be of great benefit.

Increased communication and interaction must occur between the community engaged in remote sensing research and the user community. Appropriate educational programs must be set in motion to implement the transfer of technology to the user. Without this needed education and training of the user community, satellite remote sensing information systems will advance very slowly from their present research and design status.

Landscape features are a controlling factor in the interpretation of single-date Landsat imagery because it is generally agreed that landform dictates land use more than any other major factor within the range environment. Major vegetation classes tend to transgress major geomorphic provinces as well as varying within each major land class. The type and amount of vegetation and the surface water availability also contribute significantly to major decisions regarding land use in this environment. The type of broad landform classes which can be delineated in this fashion include alluvial and floodplain lands, basin and low terrace land, plateau and upper terrace lands, and moderate to steeply sloping uplands. Only generalized maps of dominant land classes and associated vegetation types can be prepared in this environment by only interpreting one date of Landsat imagery. The use of multi-date imagery will not increase the level of detail, but it can increase the classification accuracy of major classes.

Manual interpretation of multi-date imagery can be used to assess many questions involving change. For instance, an assessment of ephemeral productivity can be made. By comparing imagery taken in the fall, prior

to the initiation of ephemeral plant growth with imagery taken at the peak of the growing period, different amounts of forage produced on different sites can be distinguished. Sites supporting a mixture of perennial shrubs and ephemerals in season can be separated from sites supporting predominantly ephemerals.

An assessment can be made of the four major events which take place within the rangeland during the spring season. First, there is the final melt of any snow pack on the major peaks of the area. Secondly, on the lower slopes and bottomlands the herbaceous vegetation grows rapidly and soon extracts most of the available moisture from the soil. Thirdly, herbaceous vegetation on drier, shallower sites begins to dry after experiencing rapid growth. And finally, surface water bodies fill with runoff water which contain a certain degree of sediment. The assessment of these changes is important because all of these factors influence management decisions of the resource specialist. Once the snow has melted, new areas are available for grazing domestic animals as well as wildlife. With the lower slopes experiencing peak forage production, rangeland animals must be managed soundly to ensure proper use of the available forage. With the lower slopes already showing signs of drying, and reservoirs at their peak, care must be taken not to overgraze those regions close to the water supply areas. With the drying of the herbaceous component, the fire danger becomes higher as the season progresses.

There are also three key changes in the range condition during the summer season which can be monitored using photointerpretation of multidate Landsat imagery. One change is the depletion of available surface water due to evaporation, animal consumption, groundwater seepage, and artificial drainage for the irrigation of small fields utilized for hay production. Another major change is the drying of herbaceous vegetation. Most of the annual type is dry by mid-to-late summer, but small quantities remain on the moist sites near springs and seep areas. A third major factor influencing a change which occurs during the summer season within the northern perennial range (northern desert shrub) is fire. Several hundred fires are recorded each year which result from either man-induced or natural causes. In addition to providing timely assessment of the water resources available for fire fighting, Landsat imagery can provide estimates of range-fire acreages, which enables the resource manager to

efficiently allocate manpower and equipment to rehabilitate the site for the renewed production of forage and to reduce erosion hazards.

Multi-stage computer classification techniques using single-date Landsat data can provide the basis for the production of a general inplace vegetation map, correctly delineating and identifying major vegetation types such as brush, mountain shrub/juniper, conifer, meadow, rock or bare ground, and water, in areas where these types dominated the spectral response of the individual pixels. Classification problems can occur in areas where vegetation/cover types are present in mixes and/or areas where the general spectral response is not dominated by vegetation or cover features. One such problem which can be very prevalent in some range environments is the identification of vegetation in areas where the total percentage of vegetation cover present is low. In such areas, the ground surface characteristics can dominate and control the classification results, not the vegetation type. In this environment, vegetation types are often not highly correlated with parent material or surface characteristics and the classification results do not indicate true ground conditions with respect to vegetation.

8. Specific Applications to Date

Landsat MSS digital data, when used in an appropriate analysis procedure, has been shown to be capable of locating and determining the real extent of various sensitive area categories. The classes considered sensitive include water, wet meadow, dry meadow, and mountain shrub. Sensitive areas larger than a hectare in size can be accurately located with automatic analysis techniques: DeGloria, et al.

The utility of multi-season coverage was demonstrated in the separation of sagebrush and cheatgrass in spring but were indistinguishable later in the year; Heronaka, et al (1976).

By ratioing spectral radiance data from Landsat (5/7), changes in growth stages and relative differences in forage production were indicated; Rouse.

Landsat data was used to supplement subjective criteria for rate and duration of stocking decisions. Single coverage was used by Drew. Colwell reported similar results and enhanced the capability by multi-seasonal coverage and by channel ratioing.

In Arizona, 31 vegetation/land types were mapped in a 3200 square mile test site using spectral data, signature change patterns, and terrain interpretation (Schrumpf).

It should be noted that remote sensing of range and forest lands through the use of Landsat data is usually supplemented by subsampling from aircraft or on the ground.

9. Summary

The salient observations made during this applications survey are as follows:

1. Data as provided by Landsat 1 and 2 add a vital dimension to ongoing information systems. Such a broad area of coverage on a repetitive basis has never been achieved before. Such a data source should be made operational if we are to have the range of information necessary to efficiently manage our forest and range resources for the future.

2. Satellite data collection systems now and in the foreseeable future are not stand-alone systems but will rely on some lower level ancillary data to reach the level of user precision demands and NASA's stated objectives.

3. Data handling problems with Landsat 1 and 2 make an ongoing operational system difficult. Providing data in usable form is essential if operational use is contemplated. Many applications have been demonstrated. However, few if any truly implementable and operational systems have been documented.

4. The Landsat follow-on satellite system designed for the 80's provides a continuum of data for ongoing applications, and adds some refinements. These refinements should provide for more accurate classification performances and broaden the data base with more quantification levels. Such improvement should render data collection activity more efficient by reducing the number of levels of data necessary.

TABLE II-3
APPLICATION ASSESSMENT TABLE

Application:

Forestry, Range and Wildlife

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Forestry		
. Forest cover types . Quantitative estimates . Land and timber condition . Geologic land forms . Productivity potential . Fire danger build-up . Monitoring change	Spectral separation of species groups. Ter: ıral/tonal discrimination. Watershed and physiographic boundaries. Land condition - wet or dry. Vegetation/land correlation. Multi-temporal overlay of data.	Spectral species differentiation is good on a broad basis -- some resolution and more spectral classes from Landsat follow-on should improve the parametric values as stated. Precise values necessary for management decisions will have to rely on sub-system support.	Not much improvement seen in resolution greater than 30 m, improvements in Landsat follow-on could be negated with poor data turn-around and dissemination. Separate data files with geographic, political, and administrative service division will help. Multi-level sources of data essential.
	Range and Wildlife		
. Vegetative mapping . Site evaluation . Monitoring capability . Range conditions trend . Wildlife and livestock water development . Fire danger . Vegetative encroachment (invader vegetation . Productive estimates	Spectral separation of vegetative associations. Physiographic delineation. Multi-temporal overlay evaluations. Change detection. Water body delineation. Vegetative densities.	Increase in capability to isolate significant vegetative associations with Landsat follow-on capability. Individual isolation still not possible -- need sub-system for great detail. Change detection and monitoring the range is feasible.	Receipt of data critical in range management. Increased grey scale discrimination with Landsat follow-on should help and broaden vegetative classification. Separate data files with geographic, political, and administrative sub-division will help.

5. Computer aided analysis of digital MSS data can only partially satisfy the information needs of most users. The improved data flow capability envisioned from Landsat follow-on, the increased ability to locate ground lines and vegetative boundaries and the capability for the user to develop an independent processing capability are all keys to a successful operational system.

6. For an operational satellite system, data collection activity should include proper formatting and geometric correction of the scene before the data are made available to the user for reduction and analysis.

D. WETLAND MAPPING AND INVENTORY

1. Background

The U.S. Fish and Wildlife Service 1956 inventory of wetlands (Shaw and Fredine, 1956) estimated that there were 74.4 million acres (29.9 million ha) of wetland in the United States: 63.5 million acres (25.7 million ha) of inland fresh wetland, 1.6 million acres (.648 million ha) of inland saline wetlands, 4.0 million acres (1.62 million ha) of coastal fresh wetlands, and 5.3 million acres (2.14 million ha) of coastal saline wetlands. The inventory included only wetlands in the conterminous United States and most wetlands less than 40 acres (16.2 million ha) in size were excluded from the survey. Since 1956, many acres of wetland habitat have been destroyed as the U.S. population increased. Also in recent years, our understanding of wetland values has increased and state and federal governments have enacted legislation to protect wetlands (wetland laws, critical areas legislation, EPA section 404, Corps of Engineers mandate). These laws generally require classification and inventory of wetlands as the first step in the protective process. In addition studies of wetland hydrology and ecology provide needed information for the management and evaluation of wetlands.

Remote sensing is becoming one of the most frequently used and practical tools for wetland inventory and mapping. It also provides some of the additional information on ecology and hydrology needed for wise resource management.

2. Present Tasks, Techniques and Data Use

The present tasks to be done are as follows:

* Wetland inventory and mapping (includes identification, classification and boundary determination)
* Wetland ecology and hydrology studies
* Wetland evaluation

These are discussed in detail below.

a. Wetland Mapping and Inventory

Wetland mapping and inventory are presently being conducted by both federal and state agencies on an operational basis. In order to inventory and map, wetlands must be defined and classified.

Because no existing classification system is adequate, individual states have defined and classified wetlands by modifying existing systems, such as the 1956 FWS inventory (Rhode Island, Massachusetts, New York and Maryland) or developing their own wetland definition and classification system (New York, New Jersey, Delaware). The resulting map or inventory products are not mutually compatible and do not allow for valid comparisons of acreage, wetland type, etc.

The U.S. Fish and Wildlife Service has recently developed a new classification system as the basis for a new National Wetland Inventory (NWI), the "Interim Classification of Wetlands and Aquatic Habitats of the United States" (Cowardin,et al, in prep.). This system will provide a uniform basis for comparison of map and inventory products at the national, regional and state levels. It should be noted that the new FWS system includes many habitats (rocky shores, beaches and deep-water bottoms) not traditionally considered wetlands. The present report will focus on the more conventional wetland concepts (vegetated wetlands).

The National Inventory will include the conterminous United States, Alaska, Hawaii, Puerto Rico and the Virgin Islands. It will probably be updated at 8-10 year intervals. The minimum mapping unit (MMU) for this task is approximately 1 acre. For clarity, the FWS definition is included here:

For the purpose of this classification system, <u>wetland</u> is defined more specifically as land where the water table is at, near or above the land surface long enough each year to promote the formation of hydric soils and to support the growth of hydrophytes, as long as other environmental conditions are favorable. Permanently flooded lands lying beyond the deep-water boundary of wetland are referred to as aquatic habitats.

In certain wetland types, vegetation is absent and soils are poorly developed or absent as a result of frequent and drastic fluctuations of surface-water levels, wave action, water flow, turbidity or extremely high concentrations of salts or other substances in the water or substrate. Wetlands lacking vegetation and hydric soils can be recognized by the presence of surface water at some time during the year and their location within, or adjacent to, vegetated wetlands or aquatic habitats.

Wetlands are also being inventoried and mapped operationally as part of the LUDA program (USGS) with update recommended every five years. The LUDA system Level II classes are Forested and Nonforested Wetland -- only vegetated classes are considered wetlands. The minimum wetland mapping unit for this inventory is 40 acres.

Presently, most wetland inventories are based upon aircraft photography supplemented by ground surveys. B/W panchromatic photographs have traditionally been used for mapping (SCS, USGS), but in recent years research has been conducted into the use of other film/filter combinations or aircraft scanner data. These include natural color, color IR, multispectral B/W and aircraft multispectral scanner. As a result of this research, coastal wetlands, and in a few cases, inland wetlands are being, or have been, operationally inventoried and mapped, using low-altitude color IR (New Jersey, Delaware, New York), natural color (Maryland), B/W panchromatic (New York, Massachusetts, Rhode Island), or ground survey supplemented with available photography (Virginia). Examples of MMU are 1/4 acre (Virginia - Silberhorn, 1975), 3 acres (Rhode Island - MacConnell, 1974), approximately 5 acres (New Jersey - Anderson and Wobber, 1973). The use of high-altitude, $>$1:60,000 scale

photographs for detailed wetland mapping at LUDA Level III or better is largely quasi-operational (McEwen and others, 1976; Georgia, MMU-1/4 acre); Carter, unpublished data, TN, MMU 1/2 acre), although Delaware's wetlands were inventoried and mapped using a semi-automated interpretation of high-altitude color IR photographs (Klemas, et al, 1974).

The techniques for mapping and inventory with aircraft data vary considerably. Examples include interpreting B/W low-altitude photographs (Rhode Island), compositing and color enhancing B/W multispectral photographs (South Carolina - experimental), interpretation from color IR photographs onto an orthophoto base (Georgia) or onto a photobase map (New Jersey/Maryland), interpretation of color, color IR or B/W photographs onto USGS 7.5-minute quadrangles (Tennessee), semi-automated interpretation of high-altitude color IR photographs (Delaware), and direct multispectral color-coded computer maps (Louisiana - experimental). Some detailed wetland classification and mapping has been done experimentally with Skylab S190 and S192 data (Anderson, et al, in press; Klemas, et al, 1974; Coker, et al, 1975; Work and Gilman, 1976).

To date, there are no documented operational programs using Landsat for wetland mapping. The use of Landsat data for wetland inventory and mapping is generally still in the experimental phase. Coastal marshes have received the most attention to date. Work by Anderson, et al, 1975; Carter, et al, 1973; Carter and Schubert, 1974; Klemas, et al, 1974; Reeves, 1973; ERL (See Rado, 1976), has demonstrated the potential of both imagery and digital data for mapping these wetlands. Little work has been done with Landsat data in inland wetlands, except that incidental to general land use mapping (Ellefsen, 1974). Experiments on the prairie potholes (Work and Thompson, 1974; Best, et al, 1974), southern swamps (Carter and Smith, 1973; Carter, 1974; Carter, et al, in press; Welby, et al, 1974), Minnesota bogs (Trippler, 1972), statewide wetland mapping in Wisconsin (Keiffer, et al, 1975), and work in progress in Tennessee Minnesota, Oregon, Alaska and other places suggest that Landsat data has potential for inland wetland inventory if spectral parameters are worked out and boundary dynamics problems are solved. As a result of current Landsat system limitations, the present FWS National Wetlands Inventory will utilize aircraft photography rather than Landsat imagery. Hopefully, future updates will be able to utilize improved Landsat data.

b. Wetland Ecology and Hydrology Studies

Many of the investigators referenced above have used aircraft data in a variety of ecological studies. Among these are studies of species composition of wetland vegetation, wetland productivity, wildlife habitat diversity, impact of man-made structures on wetlands and mosquito-breeding habitats. Comparatively few studies have been carried out on wetland hydrology and wetland management.

Landsat data have been used experimentally for similar types of studies. Gross species composition has been related to salinity in coastal wetlands (Anderson,et al, 1975; Rado, 1975), acreages of relatively pure species have been identified and related to primary productivity (Carter, 1976), and man-made structures and spoil disposal sites have been identified (Anderson, 1975; Rado, 1975).

c. Wetland Evaluation

Wetland evaluation is presently done by wetland type and vegetative composition. Studies using remote sensing to identify and map wetlands have the potential for use for wetland evaluation. A relative value model is presently being prepared for Delaware marshes (Daiber, 1976, written communication), based on plant species, maps, and other data. Wetland values are determined in many cases by a variety of criteria, such as adjacent land use, which can be assessed using remote sensing (Larson, 1973, 1975; Gupta, 1972).

3. Limitations on Using the Present Landsat System

The principal constraints on presently available satellite remote sensing systems from the perspective of utility for identification and mapping (i.e., inventory of wetlands) lie with spatial, spectral, and radiometric resolution.

a. Spatial Resolution

Current generation satellite scanners provide a nominal resolution of 1.1 acre. Usable resolution in most instances is several times less than this figure due to the interaction of scene element contrast, instantaneous field of view, boundary pixels, and other associated

problems. The linear resolution is presently a problem when considering wetlands forming long narrow zones. In order to provide satellite-derived data of sufficient spatial resolution to interface directly with and update inventories currently being planned or in progress at the national, regional and state level, a nominal spatial resolution of 1/4 acre will be necessary. Hopefully, with this level of resolution, a workable discrimination to 1 acre will be routine, and for particularly unique habitat components, 1/4 to 1/2 acre resolution may be possible.

b. Spectral Resolution

A second area where current systems become restrictive is in the ability to discriminate various wetland types. Although it has been clearly demonstrated that current generation satellite data is useful and reliable for discriminating large coastal marshes, this type of wetland represents but one of a multitude of wetland classes or types. For example, the classification system used for the current FWS National Wetlands Inventory has expanded considerably the commonly accepted concept of wetlands, and the system now includes numerous types of inland habitat previously either peripherally considered or ignored as wetlands. Most of the experience to date in spectral discrimination of wetlands has been done in coastal estuarine wetland types. There is very little experience with the multitude of inland wetland types from which recommendations for spectral requirements for discrimination of such types can be made. Therefore, although the problem can be identified, a quantitative solution is difficult to propose at this time because of the need for future research.

c. Radiometric Resolution

A third difficulty has to do with the dynamic range of the sensor within any given spectral band. Increased dynamic range will allow for finer radiometric resolution and therefore increase the probability of separation and accurate classification of closely similar spectral signatures for various wetland types (Recent Purdue and ERIM studies).

d. Desirable System Parameters

Although a large dynamic range is necessary in the data system to handle data gathered over land and water, different portions of this

range will be required for emergent and subaqueous vegetation. Therefore, an on-board or ground-controlled gain or digitization changing scheme may be useful, provided that gain settings or equivalent are transmitted.

The incorporation of even more finely divided bands (increased spectral resolution) in the Thematic Mapper (which in reality is an advanced MSS) would improve the prospects for truly operational thematic mapping addressing this and other discipline requirements. A total system would involve routine ground processing of digital data resulting in output products by theme area, thus saving end users considerable time and expense. One time thematic processing on receipt of data at the ground station and generation of specifically oriented user products would be truly a quantum jump in system utility.

In the case of wetlands, a digital product produced as described above would allow update, with very little human interaction of the digital data base which will be produced as a result of the National Wetlands Inventory. This would be a truly innovative breakthrough in the management and handling of natural resource data and would considerably simplify the task of monitoring changes within this critical habitat.

The combination of digitally stored thematic information derived routinely from Landsat data and a comprehensive natural resource geobase information system may make real-time resource assessment and management a reality.

4. Utility of Proposed Landsat follow-on Parameters

In general the adequacy and utility of Landsat follow-on parameters can be summarized as follows:

coverage	adequate
resolution	improved -- see below
spectral	improved -- see below
geographic	considerably more useful if as promised
location	considerably more useful if as promised
accuracy	considerably more useful if as promised
delay to receipt of data	not critical for mapping and inventory; excessive delay unacceptable for monitoring
repeat cycle	adequate

stereo . . . . desirable especially for small or linear wetlands in mountainous terrain

standard data products . . . . ultimately, then extraction of wetlands would be desirable; however, standard products, especially CCT, are adequate. CCT should be available for <u>all</u> areas.

sensitivity to degradations . . . . cannot be presently evaluated -- improvement, i.e. noise or atmospheric effect removal, would be desirable.

auxiliary . . . . aircraft coverage still necessary -- see below

quantization . . . . 256 levels is adequate

The increased number of spectral bands and the improvement of ground resolution to 30 m (approximately 1/4 acre) should improve the capability to map and inventory wetlands according to present legislative requirements. The maps will not have boundaries accurate for use as the basis for litigation or for conducting regulatory functions. Improvement should be seen in separation of different wetland types, once spectral and seasonal parameters, combinations of bands, and dates are established through further research. Present indications are that at least 2, and possibly 3 or 4 dates, will be needed to identify all wetland types and to determine hydrologic/vegetative boundaries.

Efficient methods must be devised to extract information on a relatively routine or pre-programmed basis. Small individual wetland inventories (county, even state) could be accomplished with present methodology and the improved parameters, but the problems of extraction of nationwide wetland information (NWI) needs additional attention. Present attempts at regional or state mapping are being concentrated on overall land-use cover and will not provide the more detailed wetland classification needed to accomplish a national inventory.

The resolution of the data provided by Landsat follow-on will not be an overkill. Present Landsat data are not sufficient for small wetlands and wetland boundaries. The promised geometric correction and map projection will facilitate the transfer of wetland information to the user. The volume of data may, however, be a problem.

a. Auxiliary Data

Until research on methodology is complete, aircraft data will still be needed to check accuracy, evaluate analysis results, and provide products of high resolution and accuracy required for ongoing operational programs. Much recent data is presently available (FWS is completing an inventory of high quality CIR photography since 1970) and it is not likely that demands for aircraft coverage will be excessive, provided the data exists for the correct season(s). However, additional aircraft coverage may be required where detailed ongoing monitoring is necessary.

Improvement in data systems, data interpretation and data processing is extremely desirable. The anticipated quantity of data foreshadows the urgent need in this area.

b. Orbit Parameters

a) 9:30 am vs. 11:00 am equatorial crossing

Specular reflectance and sunlight problems increase as the sun approaches the zenith; species of discrimination may improve with higher sun angle. Chances for water penetration become poor. For some areas the cloud cover tends to increase later in the day. It is not clear that the negative effects are compensated for by a decrease in shadowing. In addition, the comparison between present images and the new images will not be facilitated by this change in time.

b) Decrease in altitude of orbit: This will cause a decrease in orthography and uniformity of spectral radiometry as viewing angle increases and processing will be more complicated and costly. Multi-temporal comparison with previous data will also be difficult.

5. Archiving

Questions still remain concerning what data will be retained, what data format will be used, and what data will be distributed to users. Perhaps high density tape storage of all images meeting established criteria (cloud cover, etc.) should be archived, rather than photographic or CCT data. A quantum jump in the number of browse facilities and distribution centers will be needed. For wetlands, at least, there are local as well as regional and national users.

6. International

Satellite data have great potential for global wetland inventory where very little information exists. Two programs having potential use for such data are the Man And the Biosphere program and the International Union for the Conservation of Nature program on wetlands.

E. COASTAL ZONE AND SHORELINE MAPPING AND INVENTORY

Significant progress has been made in recent years in demonstrating the use of electromagnetic remote sensing instruments to derive information about the character and conditions of coastal water. The present state-of-the-art for collecting, processing, and analyzing remote sensor data has evolved from aircraft and spacecraft experience in which Landsat data have been a significant factor. In particular, Landsat imagery has been useful in mapping and surveying coastal features by state, federal and private interests involved in coastal management activities which have been accelerated since the U.S. Coastal Zone Management Act of 1972.

Techniques have been developed for providing baseline data for coastal landforms and land use inventories. Models for computing shoreline dimensions and displaying changes due to storms, erosion and man-made causes have been developed from Landsat data. Although low altitude aerial photography is superior in efficiency, accuracy and objectivity to Landsat imagery in measuring detailed shoreline changes, satellite data is superior for measuring large-scale regional features such as shoreline form. Angular orientation, sinuosity, and curvilinear features are examples where satellite perspective and overview offer advantages which are superior to aircraft imagery.

In addition to the coastal land inventories and shoreline applications, the physical properties and processes of coastal waters have been observed and measured by remote sensors, including the mapping of sub-surface topographic and bathymetric features, location and measurement of pollutants, areas of high bio-productivity using color indications of chlorophyll concentration, surface circulation and currents through tracing of sediment and dye movement, shoal locating and depth determination. There is evidence that quantitative sediment processes

may be mappable for Landsat. Remote sensing of salinity and fish oils are examples of less successful measurements from aircraft which appear infeasible from spacecraft.

1. Shoreline Dimensions and Changes

Storm-induced changes in shape, dimension and location of shoreline features are dramatic, rapid and often considered disastrous. The storm of 1962 which affected the east coast of the United States from South Carolina to Massachusetts caused the loss of life, millions of dollars of investments in homes and businesses, and created a multimillion dollar requirement of federal, state and private funds to partially restore the shoreline to its pre-storm condition and provide protection against further storm damage. Such storms, although unusual, do occur yearly on a smaller scale and create problems for those who live on or use the shoreline. Moreover, the normal day-to-day forces, i.e. waves, tides, currents, constantly alter the shoreline and cause erosion on one portion, accretion in another and siltation of harbors, inlets and estuaries.

Presently, the means to measure such changes use conventional methods of topographic and hydrographic surveying techniques which are time-consuming, expensive and limited in aerial scope. These methods, because of the inherent restrictions of men and equipment, cannot measure changes in the shorelines on a broad regional basis and cannot be accomplished repetitively on an economically sound basis. The use of aerial photography has allowed a wider area of coverage of the shoreline to be made, but to a certain extent still suffers the restrictions of the conventional techniques. Both methods are restricted to fair weather conditions and are usually aimed at a site specific problem.

Use of Landsat imagery, with its repetitive and large aerial coverage, has shown that it is feasible to detect changes in the shoreline but has been restricted in accurately measuring the dimensions of shoreline features and changes that occur in such features with time because of the limited spatial resolution (Miller and Berg, 1973). Changes such as those made by the storm of March 1962 are presently within this resolution, but the normal day-to-day modifications of the shoreline are smaller than the specifications of spatial resolution of the existing satellites.

Increased spatial resolution of the proposed Landsat will allow a greater capability to measure the dimensions of shoreline features and changes in such features but still is not adequate to do so accurately. Most coastal structures (breakwaters, jetties, beaches, groins) have limiting dimensions of 7 to 9 meters. Major erosion of beaches approaching 15 meters or less are common and it would be advantageous to be able to accurately detect and measure such changes.

2. Coastal Circulations, Currents and Sediment Transport

Most of the sediments which compose the shoreline are derived from upland areas, delivered to the shore by rivers and streams, distributed alongshore by currents, deposited and eroded by waves and currents, and are normally in constant motion. Movements of individual sand grains may in themselves be small, but generally the shoreline is in a state of instability. The prime forces causing this motion are waves and wave-induced littoral currents. Natural features such as inlets and river mouths and man-made features such as harbors interrupt this movement of littoral materials and create problems for man -- in one place, too much material and in others, not enough.

In using the shoreline, it is imperative that a thorough knowledge of the movement of littoral materials be available for proper planning and for use of the coastal zone. If sufficient knowledge is not available, improper and incorrect solutions for problems can be made or misleading applications of solutions can be selected.

The construction and maintenance of navigation facilities for industry and pleasure is a multi-million dollar business, and the successful continuation of such facilities depends on man's attempt to alter nature by either dredging littoral materials from harbors or construction of massive coastal structures such as jetties or breakwaters. Too often a solution which did as it was intended at a specific location is selected for another location, only to fail from a lack of understanding of the hydrodynamic forces present in the coastal areas.

The use of Landsat imagery has assisted in expanding the knowledge of nearshore water circulation and in some respect, by inference, the movement of littoral materials. Imagery has revealed the aerial extent of sediments discharged by rivers under both normal and flood conditions;

the circulation of coastal waters and the sediments suspended in such waters; the effect of natural and man-made coastal structures in diverting or converging currents, the effect of thermal-enhanced discharges from electrical generating plants and the dispersal of man's wastes dumped at sea. Prior to Landsat, only indications of such effects could be photographed and measured, largely because the physical size of circulation patterns were beyond the scope of the existing equipment. Landsat, with its macro-scale capability, revealed these features sometimes in their entirety.

Improvements in operational equipment of Landsat can only improve and broaden our understanding of coastal waters circulation, coastal currents, the movements of littoral materials and the deposition of man's wastes in nearshore coastal area.

3. <u>Coastal Land Form, Land Use, and Land Cover</u>

The Department of Environmental Sciences, University of Virginia, has studied coastal land use and modified a U.S. Geological Survey land use classification into 19 categories. High altitude color -- infrared photography was used as the data base for the study.

Analysis of the land use and land cover maps provides a stratification of shore areas into similar environmental regions. Change-making processes for each land use and land cover type were analyzed as a basis for estimating time periods for monitoring the different landscape elements.

Elements of the landscape are altered less frequently as one moves inland. Tidal actions and erosion are examples of natural change factors which prevail less as one goes inland. Man's actions in modifying the environment are more random and depend on the level of his activity. Based on the alteration frequency, frequencies of monitoring requirements are greater nearest to shorelines. Based on the analysis of high altitude aircraft data, this study recommends the use of Landsat imagery to gain metric imagery over large areas at greater frequencies and at less cost than aircraft data can provide. Landsat data can fulfill these needs except where higher spatial resolution or greater than 9-day observation frequencies are needed.

Except for the later (11:00 am EST) equatorial crossing proposed for Landsat follow-on, the increased resolution and repetitive coverage

will be an improvement over Landsat C. Increased clouds over land and sun glint over water which occur with sun angles after 10:00 am LST will decrease the utility of the Landsat follow-on for water sites.

4. Water Mass Characteristics

The Marine Ecosystems Analysis (MESA) program in the National Oceanic and Atmospheric Administration (NOAA) has found that thermal and color sensors on satellites (NOAA, Landsat) and aircraft adds a new dimension to coastal analyses of dispersion of pollutants and sediments. Identification of water mass characteristics such as chlorophyll content, thermal boundaries and circulation patterns are detectable from satellites.

In particular, the NOAA MESA program conducted extensive remote sensing experiments in the New York Bight in April 1973 and April 1975. Landsat imagery and aerial multispectral imagery were obtained concurrently with surface measurements of chlorophyll, temperature, currents, and counts of sediments and sewage material. Enhancements of these multispectral images show that concentrations of pollution, chlorophyll and sediments can be delineated. Enhancement techniques have been developed by the Environmental Research Institute of Michigan (ERIM), General Electric Corp., and others. The comparative surface oceanic properties measurements were made by the National Environmental Satellite Service (NESS). Results of the New York Bight study of applications of remote sensing to water mass characteristics have been published by ERIM and NESS. There is high probability that Landsat follow-on Thematic Mapper will, except for the later equatorial crossings, enhance the utility of Landsat for coastal oceanic applications. The increased spectral and spatial resolution can only increase the reliability of Landsat follow-on data for marine coastal applications; the 9-day coverage will obviously allow better data for circulation and dispersion studies. The marine community is opposed to sun angles greater than those that occur with equatorial crossings after 10:00 am LST. Increased cloudiness and reduced oceanic data and increased sun glint after 10:00 am LST will render ocean images practically useless.

5. Hydrographic Charting

The Defense Mapping Agency, in conjunction with the international

hydrographic community, has the responsibility of providing accurate and inexpensive charts for marine navigation. A significant problem is looming on the technological horizon, for which Landsat Multispectral Scanner (MSS) data may prove to be the only effective solution. Within the next decade, low cost, Global Positioning System (GPS) receivers will be providing ships with real time, precise positional data. Navigators will use this data to plot their courses and for their navigation. Current charts, for the most part, cannot support this type of navigational accuracy. Currently, only about 20% of the world's oceans have been adequately surveyed with sonar and modern navigation systems. Additionally, there are vast amounts of ocean areas that have never been surveyed by any means. There are literally thousands of "doubtful dangers" marked on charts that have never been verified. (Doubtful dangers are possible hazards noticed by mariners and reported to the responsible hydrographic office where, in the interest of navigational safety, the feature is marked on the charts.) Some of these sightings date back to the 1800s and most have never been verified or disproved by an official survey and are still shown on the charts. Typical reports describe discolored water, breakers, volcanic action, anomolous soundings, etc., and the associated position -- as best they were able to measure it. Islands within 100 kilometers of the U.S. coast have been reported to be as far as 2 1/2 km off from their charted positions.

How then can the charts be updated to support worldwide precision navigation? The survey resources of the U.S. Naval Oceanographic Office are limited and must be dedicated to high priority survey areas. They have only two coastal surveying ships which survey coastal waters (within 180 km from shore), straits and passages, harbor approaches, harbors, shoals, reefs, etc. Each ship has four survey launches and one helicopter. The total cost of operation for the two survey vessels in 1973 was 9.1 million dollars for 180,000 linear km surveyed. (Note that the great number of parallel tracks must be run to cover the area surveyed; thus the total area covered per year is quite limited.)

The present Landsat Multispectral Scanner (MSS) is providing a partial solution to this dilemma. The recent joint NASA-Cousteau Experiment in the Caribbean has proved the capability to chart significant shoal features with MSS data. During the experiment, depths of shoals were determined from the satellite data and verified by ships on site.

Depths to 22 meters were measured with 10% accuracy and other shoals as deep as 40 meters were detected. Evaluation of worldwide water transparency indicates that this approach can be used in most oceanic waters away from the continental shorelines and in some instances and areas, even these coastal waters can be plumbed. The hydrographic community has an urgent requirement to exploit this source of information.

Application areas for current Landsat MSS data are:

(1) Hydrographic charting: This includes mapping of islands, reefs, and shoals in remote ocean areas. (Also included is the use of MSS data to evaluate existing charts.) National map accuracy standards for resolution and accuracy are:

Scale	EIFOV	90% Horizontal Accuracy of Features
1:25,000	1-20 m	25 m
1:250,000	5-60 m	125
1:1,000,000	20-240 m	500

Most hydrographic charting in these remote areas would be at 1:250,000 or smaller. The current Landsat MSS comes close to meeting the requirements for these scales. Additionally, most shipping using these charts will have drafts of less than 22 meters (73 feet) and the recent NASA-Costeau experiment in the Bahamas has shown the feasibility of application to these depths for detecting shoals. Additional evaluation of worldwide Secchi disk data indicates that the water transparency is equal to or exceeds that found in the Bahamas for most of the aforementioned remote areas.

(2) Presurvey for planning of Hydrographic Surveys; this requirement involves charting from 1:10,000 to 1:100,000. The capability to perform accurate presurveys allows the expensive survey operations to be optimally performed. A commonly quoted figure is that the survey boats spent 50% of their time in shallow water collecting 10% of the data. With presurvey by Landsat MSS, only those navigation channels clearly open to most vessels need be surveyed.

(3) Validation of Doubtful dangers; the scale of resolution for this requirement could be as small as 1 meter for a reported "rock awash" to 100 m for a reported sandbar or islet. Horizontal accuracy would be the same as that required for the largest scale chart covering the area.

An assessment of current Landsat capabilities vs. the Thematic Mapper follows. (This assessment is not totally driven by National Map Accuracy Standards; in some areas the charts are so far from meeting the standards that an interim chart update from Landsat MSS data which does not meet the required accuracies either will probably be issued. However, this product will be so much better than the present product that navigational safety will be insured. Some islands have been reported to be up to 26 km from their charted positions!)

ASSESSMENT OF CURRENT LANDSAT CAPABILITIES VS THE THEMATIC MAPPER

Characteristic	MSS	Thematic Mapper
Spectral Bands	Adequate -- IR shoreline delineation & .5 - .7 μm water penetration	Good -- IR plus 2 bands with water penetration capabilities & optimized band at .45 - .52 μm.
EIFOV	Fair -- cannot see rocks or small reefs	Better -- may even be able to position off-shore oil platforms
Quantization	Fair -- better in high gain mode -- more discrimination of water depth	Much better -- much more discrimination of depth variations
Recorder	Required for acquisition over remote ocean area but limited lifetime is hindrance	Required -- especially away from ground stations and if Direct Transmission (DT) is not possible or if DT has gaps or excluded areas out of reach of ground stations

Characteristic	MSS	
Crossing time (sun angle)	9:30 am -- Excellent -- sun glint is a problem only for medium or high sea states	11:00 am -- TERRIBLE -- probably would exclude about 50-75% of useful water penetration data! Sun elevation in excess of 55° with wind speeds in excess of Beaufort 5 (fresh breeze or 10 m/sec) will cause much data in the equatorial zone to be useless for water depth determination
Orbit Ephemeris	Not usable for mapping. Ground references are required to get adequate horizontal accuracies	A precise ephemeris would contribute greatly to mapping accuracies from the TM
Attitude histories	Inadequate	A detailed, precise attitude record would permit application with precise ephemeris to adequately position remote islands & reefs with respect to a worldwide geodetic reference system
Cartographic Capability	Good in relative sense or where ground control is imaged. Poor in open ocean away from land	Good -- if precise ephemeris and attitude records are available, and if internal system geometry is not degraded

Support Services — Both systems have the same requirement here in that low cost film products of high quality will be required to assess areas for changes with respect to existing data prior to initiating the expensive digital processing operations. (Consider buying a CCT and processing to extract shoals, only to find 34,000 square km of empty ocean.)

There is a need for precise reconstruction of the data, geometrically, without resampling the pixels for some purposes. This is especially true when pushing the data to the extreme limits of resolution to locate mining platforms, shipwrecks or small reefs.

Data formats should be internationalized so that data collected by foreign ground stations can be processed without reformatting.

6. Summary

The following Landsat Parameter Assessment Table points out the adverse effect of the proposed higher sun-angle on all over-water sites. Sun glint or glitter will increase to the extent that, even on calm smooth seas, the water sites information will be reduced considerably. The blue-band (450-520 nm) will have a 50-70% degradation of available data for shoal detection if the equatorial crossing of the Landsat occurs after 10:00 am LST (sun elevation in excess of 55^{o}). It is timely to indicate that the most recent research (Polcyn, ERIM, 1975) finds 470-520 nm to be optimum for water penetration when 70 nm band width is used; however, the .45-.52 and .52-.60 bands are suitable for shoal detection. If water targets are of any importance, the above sun-angle and blue-band recommendations must be considered. The proposed higher sun-angle is the most serious problem for water target sites and, as indicated elsewhere in this report, the later proposed equatorial crossing is expected to confront the adverse condition of increased cumulus cloud cover for many terrestrial sites as well.

TABLE II-4

APPLICATION ASSESSMENT TABLE

Application:

DIMENSIONS AND CHANGES

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
Beach areas -- changes over time Retreating cliffs Landsliding along coastal cliffs "Saved" areas at erosion-control structures	Repeated images of land-sea boundary Down current plumes relationship to known, fixed references " "	Major changes are detectable and measurable; most of the real cases are below the threshold of detection except over multi-year periods.	Local on-site detection, and low altitude aerial photos are required for any useful evaluation, or planning remedial action. Water-penetrating bands. Corps of Engineers among others has information
Hydrographic Charting			
Shorelines, reefs, islands, shoal mapping. Positioning of oil and mining platforms; reefs with respect to islands in archipelagos.	IR imagery for shoreline and optimized water penetration bands from .45 to .57 μm, radiometric sensitivity and resolution for depth discrimination.	With exception of orbit height and sun angle, Landsat follow-on meets a great percentage of present requirements.	NASA/Cousteau Expt. DMA Hydrographic Center Work USGS Carto. Eval. ERIM Studies NASA GSFC Studies
Land-Use Landcover			
Grass and pasture vegetated sand flats, vegetated dunes, forests, estuaries, bays, ponds, marshes, mud flats, beaches.	Images of land water boundaries, vegetation identification.	Satellite overview, 9-day Landsat follow-on coverage and increased spatial resolution will provide.	High altitude aircraft experiment indicate that Landsat follow-on can obtain parameters needed.
Water Characteristics			
Color delineations; Thermal boundaries and patterns; Depth penetration.	Chlorophyll; yellow substance; sediments and pollutants.	Areas of color difference can be seen if contrast is great; false color enhancement of imagery and digital tape data delineate color features.	Color enhancements and digital gray-scale readouts relatable to water properties need upgrading.
Coastal Circulation Currents & Sediment Transport			
Major Coastal land forms; Harbors; Inlets; Water color contrasts.	Suspended sediments; River/tidal discharges; Variations in water color.	Large scale features are detectable and measurable.	Color enhancement desirable. Ground truth is required for quantification of image data Water penetrating capability desirable.

The second most serious objection to the Landsat follow-on is the loss of data analysis continuity. Even though the Landsat follow-on MSS bands are the same as earlier Landsats, the geometric (orbit, sun-angle, etc.) parameters have been changed. If a technology transfer MSS to TM is to be performed, the TM should be flown with the MSS, but with the Landsat geometry. Then the users can determine what the effects of changing the spectral bands would be.

A third significant user-related problem is program continuity. Define the system parameters, fly it, and keep it operational with the same base parameters for 10 or more years. Make the acquired data available to the user community responsively, inexpensively and in easily exploited formats.

7. Recommendations

From the viewpoint of the Coastal Zone and Shoreline Mapping and Inventory sub-application panel, the Landsat follow-on should maintain the same orbital parameters, especially equatorial crossing time as Landsats 1, 2 and C. This will maintain a continuity of data so that the Thematic Mapper bands can be truly evaluated and related to the data accumulated during the Landsat program. The blue band proposed for water penetration is expected to prove valuable for marine users. Low cost and rapid dissemination for both film and tape products is necessary for optimum exploitation by both domestic and foreign users.

F. MAPPING AND CARTOGRAPHY

1. Landsat Definition

This report is based on four aspects of the Landsat program as follows:

(1) The actual performance of Landsat 1 and 2

(2) The expected performance of Landsat C as now defined

(3) The expected performance of Landsat follow-on as now defined by NASA

This definition includes the following:

a. The MSS and multichannel Thematic Mapper in a circular Sun synchronous orbit of 705 km

b. 185 km swath width (same as Landsat 1, 2, and C)

c. 11:00 am crossing of the descending mode

(4) Landsat follow-on, defined by this subpanel, must be an economically viable operational satellite.

2. Cartographic Characteristics

Landsat characteristics which are relevant to mapping and cartographic tasks are summarized below (Colvocoresses, 1973 a, b, 1975; Kratky, 1974).

(1) Coverage and long life. In one year, cloud-free coverage of the entire United States was obtained. Landsat 1, 2, C, and follow-on promise to provide systematic coverage of the Earth for over a 10-year period. Seasonal coverage is also being accomplished.

(2) Orthogonality. The 185 km wide sweep of the current MSS represents a scan angular coverage of only 11.52 degrees. Due to this nearly vertical view, relief displacements are minimal and the images are well suited to small-scale planimetric mapping and revision. If the altitude is reduced to 705 km, as planned for Landsat follow-on, relief displacement will increase by as much as 32 percent due to the greater sweep angle required to record the 185 km path width, and this displacement will complicate mapping. Increased differences in the Sun-object-satellite angle across the image due to the greater sweep angle will also be detrimental.

(3) Geometric fidelity. The relative positional accuracy obtained with Landsat imagery meets or approaches that required for U.S. National Map Accuracy Standards (NMAS) for 1:500,000 scale cartographic products (1:250,000 scale under ideal conditions). By decreasing the IFOV from 79 m (Landsat 1, 2) to 30 or 40 m (Landsat C RBV, follow-on), map accuracy can be somewhat improved.

(4) Multispectral images. The MSS bands 5 (red) and 7 (infrared) have proved most useful for recording land features and land-water interfaces. Band 4 (green) provides water depth penetration under optimum conditions to beyond 20 meters and thus can assist in the charting of shallow seas. Band 4, when enhanced and combined with bands 5 and 7 in

analog or digital form, also provides for the differentiation of both dormant and growing vegetation. The thermal band of Landsat C and the addition of an optimized water penetration band on Landsat follow-on will enhance thematic and shallow sea mapping.

(5) Suitability for Automation. The MSS provides continuous coverage along a 185 km wide strip, and this coverage can be fitted to a Space Oblique Mercator (SOM) projection with a distortion generally less than 1:10,000 (Colvocoresses, 1974). Repetitive coverage and the transmission and generation of images of cartographic quality by electronic means provide a basis for automating the production of small-scale cartographic products. The compatibility of (NASA) planned Landsat follow-on data with mapping systems developed to utilize the data from Landsat 1, 2, and C is questioned.

3. Specific Applications

Applications of Landsat data for mapping tasks include:

(1) Shallow-sea mapping and charting
(2) Aeronautical charting
(3) Small-scale image mapping
(4) Map revision
  a. revision of bold features
  b. revision of cultural features
(5) Thematic mapping

Each of these applications is considered in the following paragraphs.

(1) Shallow-Sea Mapping and Charting (See also the Section on Charting under E. Coastal Zone and Shoreline Mapping and Inventory)

The Defense Mapping Agency Hydrographic Center (DMAHC), in conjunction with the international hydrographic community has the requirement of producing charts suitable for marine navigation. Pertinent application areas for current Landsat MSS data include:

a. Hydrographic charting of islands, reefs, and shoals in remote tropical ocean areas, and verification of existing charts.* Most nautical charting in these remote areas is at 1:250,000 or smaller scales, for which the Landsat data is appropriate. Additionally, most shipping using

* During the spring of 1976, DMAHC received Landsat imagery of the Chagos Archipelago (Indian Ocean) which will serve as a basis for revision of nautical charts. This coverage reveals uncharted shoals and that some charted features are positionally in error by over 15 kilometres.

these charts will have drafts of less than 22 meters (73 ft.) and the recent NASA/Cousteau experiment in the Bahamas has shown the feasibility of detecting shoals to this depth from Landsat data (Polcyn, 1976; Polcyn alnd Lyzenga, 1973; and Ross, 1973). Worldwide Secchi disk data further indicates that the water transparency in many other ocean areas is generally equal to that found in the Bahamas (Frederick, 1970).

b. Presurvey for planning of hydrographic surveys. Detailed hydrographic surveys generally involve charting at 1:10,000 to 1:100,000 scale and the performance of accurate presurveys allows the expensive boat survey operations to be optimally performed. A commonly quoted statistic is that the survey boats spend 50 percent of their time in shallow water collecting 10 percent of the data. With presurvey by Landsat data (in areas of appropriate water clarity and other conditions), channels open to most vessels can be located and defined for detailed surveys, and thus boat survey time can be materially reduced. This in turn increases the cost effectiveness of the survey operation. In general, the orbit and sensor parameters of Landsat 1, 2, and C are well suited to the nautical charting tasks described above. Desired improvements include reduced sensor IFOV, an optimized water penetration band and improved orbit ephemeris and satellite attitude data. While defined Landsat follow-on parameters meet these requirements, the proposed equatorial crossing time of 11:00 am, coupled with the greater sweep angle, will result in excessive Sun glint and precludes the use of the data for nautical charting of tropical areas (Strong, 1971; Strong and Ruff, 1970).

(2) Aeronautical Charting

United States aeronautical charting agencies include the National Oceanic and Atmospheric Administration (NOAA) and the Defense Mapping Agency Aerospace Center (DMAAC). Landsat data have proved most useful for revising the representations and positions of features such as mountains and water bodies, and for the depiction of vegetation boundaries. For many remote and poorly mapped areas of the world, Landsat provides the only readily available data from which small-scale charts can be compiled or revised. The most significant advantage offered by Landsat follow-on, as defined by NASA, appears to be the smaller IFOV

of 30 m. However, the planned orbital altitude of 705 km and 11:00 am equatorial crossing are detrimental to charting tasks.

(3) Small-Scale Image Mapping

Image maps and mosaics have been produced from Landsat data by numerous agencies (Instituto Brasileiro de Geografia e Estatistica, 1973; (Bolivia) Instituto Geografico Militar, 1973, 1974; Survey of Israel, 1973; USGS, 1973-76). In the United States, the principal agencies mapping with Landsat data include the U.S. Geological Survey (USGS) and the Soil Conservation Service (SCS).

The regularity and consistency of the Landsat 1 and 2 orbit has allowed a set of 251 nominal ground tracks to be established and plotted on a map of the Earth. Image centers are generally repeated to monitor coverage over the nominal scenes thus defined. These nominal Landsat scenes do not overlap and each scene is identified by the geodetic coordinates or by a path/row number. The system, which is of Canadian origin, is adaptable to worldwide use and is computer compatible.

The nominal scenes described above form the basis for the image format map series (McEwen and Schoonmaker, 1975). Image format maps have been printed in arbitrary color at a scale of 1:500,000 and represent a composite of the spectral bands for a particular scene. On the image format map, grids are fitted so that positions can be referenced to meet or approach U.S. National Map Accuracy Standards (NMAS; Chapman, 1974).

Mosaics have also been prepared from Landsat imagery, including those of New Jersey, Florida, Arizona and Georgia at 1:500,000 scale (USGS), and of the entire United States at 1:1,000,000 scale (SCS). These mosaics are impressive and represent a new concept of small-scale image mapping (Hooper, 1974; Anderson, 1975).

(4). Map Revision

Revision is an integral part of all mapping and charting programs. Adequate image resolution is a primary prerequisite for map revision tasks and Landsat 1, 2, and C imagery obtained with the MSS IFOV of 79 m is only adequate for revising landforms, vegetation patterns, hydrological features, and other relatively bold items (Welch, 1973 a, b; Fleming and Sebert, 1974; Mott and Chismon, 1975). Revision of cultural features

such as roads, railways, towns, etc.,is not generally possible with current Landsat data, nor will the smaller IFOV of 30 m planned for Landsat follow-on be sufficient for revision of cultural detail. In no case can Landsat be effectively used for the revision of land topography (contours).

(5) Thematic Mapping

Thematic maps provide information about the distribution and aerial extent of various classes of objects and are often produced without concern for specific map accuracy standards (Edson, 1971; Smith, 1973). Automated (autographic) theme extraction has been applied to water, vegetation and snow; and numerous thematic maps using manual and automated means are being produced by various state and federal agencies. Because of the requirement for discrimination based on radiance levels in the different spectral bands, the addition of blue, reflective infrared, and thermal infrared bands as planned for Landsat follow-on may prove beneficial. The desirability of increasing the gray scale to 256 levels (eight bits) is useful for the thematic classification, but has no effect on cartographic applications.

4. Conclusion and Recommendations

The Mapping and Cartography panel has evaluated the parameters of Landsat 1, 2, C, and follow-on, and these evaluations are summarized on the attached tables. With respect to the Landsat follow-on, the basic mission parameters defined by NASA are unacceptable for many cartographic applications.

Cartographers, and those whose work depends on cartographic presentations of the Earth at the smaller scales, are requesting an operational system based on the following considerations:

1. An economically viable system
2. Continuity with respect to Landsat 1, 2, and C
3. Spatial and spectral resolution that are meaningful to them
4. A data flow that is manageable
5. Completely open access and availability
6. Near-real-time reception of data on a fully global basis

7. Suitability for automation

8. Expeditious dissemination in digital (tape) and optimum analog (image) form at reasonable prices

It is believed that these considerations and applications can be met by defining Landsat follow-on as follows:

1. Time frame - 1980-on (for a minimum of ten years)

2. Orbit, 99 degrees, same as Landsat 1 and 2

3. Altitude, 919 km, same as Landsat 1 and 2

4. Time of day, 9:42 am at descending mode, same as Landsat 1 and 2

5. Angular coverage, 11.52 degrees, same as Landsat 1 and 2

6. Ground swath, 186 km, same as Landsat 1 and 2

7. Coverage cycle, 18 days, same as Landsat 1 and 2

8. Sensor, solid state linear array, if proven

9. Resolution cell (IFOV), 80 m, except for a red band with 20-40 m IFOV

10. Spectral response -- one band that optimizes water penetration and discrimination (i.e., 0.47 to 0.57 μm); one band in the red (0.6 to 0.7 μm) of smaller IFOV in the 30 to 40 meter size range; one band in the near IR (0.7 to 1.0 μm); radiometric sensitivity and dynamic range at least equal to Landsat 1 and 2.

11. Transmission, direct to ground stations or communication satellites

12. Retransmission via communication satellites

13. Dissemination

    a. original data in high density digital tape (unresampled) form

    b. film imagery geometrically corrected but unresampled (bulk) imagery in same form and format as for Landsat 1 and 2

    c. precision processed tapes, registered to the Earth's figure whenever possible

d. precision-processed imagery, registered to the Earth's figure whenever possible

e. all of above to be available to users (at the processing facility or in the mail) within 7 days

It should be noted that an operational Landsat, as defined above, will meet many small-scale cartographic requirements on a worldwide basis. It will not, however, provide either topographic (elevation) data or cultural detail. Both are required and an operational Landsat must be supplemented by other spacecraft and/or aircraft programs which provide such data.

It is also noted that many needed experiments of cartographic value cannot be carried out on an operational Landsat. Therefore, it is recommended that experimental space flights continue but at this time they should not have as high a priority as an operational Landsat which is urgently needed to help solve many of the real problems besetting mankind.

G. SURFACE MINING EXTENT AND RECLAMATION MONITORING AND INVENTORY

1. Introduction and Laws

By way of introduction it must be pointed out that in this environmentally conscious period, one cannot disassociate surface mining and reclamation procedures. Historically, and even in recent years, examples can be cited where surface mining has been done without any or with minimal attempts to reclaim the disturbed areas. This is no longer true since most states now require that reclamation plans be submitted prior to issuing mining permits. There are presently (March 1976) thirty-five states that have state surface mining regulation acts. Some of these laws have gone into effect recently. Among the most recent have been South Carolina, Georgia, California and Texas. On the federal level, the Congress again attempted to establish strip mining standards for coal and other minerals. Despite two presidential vetoes, the House recently reconsidered a bill (HR 9725) nearly identical to earlier bills vetoed in 1974 and 1975. Eventual passage of such a bill would require reclamation of all strip-mined lands. On March 23, 1976 the House Rules Committee tabled a request for floor consideration.

TABLE II-5
APPLICATION ASSESSMENT TABLE

Application:

MAPPING AND CARTOGRAPHY

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Shallow Sea Mapping and Charting		
Location of shoals, islands, coastal land/water contacts and hazards. Verification of reported sub-surface topography. Water depth. Evaluation and revision of charts.	Suitable spatial, spectral, temporal and radiometric resolution.	Not feasible because of sun angle and other orbit parameters. Improved performance if earlier orbit time adopted.	Optimum water penetration band and higher spatial resolution desired. Landsat 1 and 2 orbit parameters are optimum.
	Aeronautical Charting		
Location of features for navigational purposes. Compilation and revision of aeronautical charts.	Suitable spatial, spectral, temporal and radiometric resolution.	Not feasible because of sun angle and other orbit parameters. Improved performance if earlier orbit time adopted.	Landsat 1 and 2 parameters adequate except for spatial resolution. Elevations cannot be determined.
	Small-Scale Image Mapping		
Images suitable for mapping at scales of 1:250,000 and smaller	Suitable spatial, spectral, temporal and radiometric resolution.	Not feasible because of sun angle and other orbit parameters. Improved performance if earlier orbit time adopted.	Landsat 1 and 2 orbit parameters desired. Higher resolution is beneficial.
	Map Revision-Bold Features		
Identification and positioning of map features.	Suitable spatial, spectral, temporal and radiometric resolution.	Not feasible because of sun angle and other orbit parameters. Improved performance if earlier orbit time adopted.	Landsat 1 and 2 adequate.
	Map Revision-Cultural Features		
Identification and positioning of map features.	Suitable spatial, spectral, temporal and radiometric resolution.	Not feasible because of sun angle and other orbit parameters. Improved performance if earlier orbit time adopted.	30 m pixel better but still inadequate.
	Thematic Mapping		
Classification and positioning of designated theme.	Suitable spatial, spectral, temporal and radiometric resolution.	Not suitable for many themes	

2. Surface Mining Regulatory Objectives

Landsat research efforts in surface mining have been conducted with the following objectives:

To demonstrate Landsat capability of mapping acreages stripped and disturbed by surface mining operations.

To monitor changes in stripping and secondary effects of mining on the environment.

Attempts have also been made to detect, identify and map the secondary effects of surface mining such as erosion, vegetative stress and sedimentation.

3. Present Applications of Landsat Data

In reviewing this area, the first question that should be answered is, "To what extent is Landsat-type data being used on an operational basis in monitoring surface mining and reclamation activities by state regulatory agencies?"

In order to provide an answer to this question, on March 23, 1976 a data user survey in behalf of the ASG was conducted throughout the 50 states. Questions were sent to 38 Bureau of Mines State liaison officers who cover the entire United States. The response to this survey showed that no state regulatory agencies are using Landsat data on an operational basis to monitor surface mining. Maryland and West Virginia have been the most active in conducting research in this area. The Maryland work is cited later in this section.

Remote sensing research using Landsat data to monitor and map surface mining areas has been conducted in the following areas: Clearfield County in Central Pennsylvania (Alexander and Dein, 1973); Southeastern Ohio and Eastern Tennessee (Rogers and Pettyjohn, 1975); the Eastern Interior Coal Basin and the anthracite coal basins of Northeastern Pennsylvania (Amato, et al, 1975); Western Maryland and West Virginia (Anderson, et al, 1975); thirty coal mine sites in the Northern Great Plains (Montana, North Dakota and Wyoming) (EPA, 1975) and Aiken County, South Carolina (Sheffer and Beam, 1976).

Commenting on all these studies to date, it is the general

conclusion of most researchers that Landsat remote sensing data, combined with appropriate low and high level aerial data (ground truth), could be a useful tool in monitoring and mapping surface mining and reclamation progress. All of the research conducted used analysis of digital values of the reflectance levels obtained from computer compatible tapes (CCTs) for the areas involved. The greater the surface areas under study, the higher the degree of accuracy obtained between comparisons of ground truth and digitally calculated areas from Landsat images. In dealing with small areas (several acres or less) the limiting factor for Landsat data use is the spatial resolution of the sensors.

In an early study (Alexander and Dein, 1973) done in Clearfield County, Pennsylvania by Penn State University's Office of Remote Sensing of Earth Resources (ORSER), the usefulness of ERTS-1 (now known as Landsat-1) data was assessed for monitoring strip mining and reclamation and detecting areas affected by acid mine drainage. Using computer analysis of multispectral scanner (MSS) data for September 6, 1972, it was possible to map into seven categories the extent and type of strip mining and reclamation and also determine surface areas affected by acid mine drainage.

The Ohio study (Rogers and Pettyjohn, 1975) using Landsat CCT tapes from 21 August 1972 and 3 September 1973 reported the feasibility of using Landsat data to map and monitor strip mining and reclamation (maps of 1:24,000 to 1:250,000 scales) at a cost one-tenth of conventional mapping techniques.

The categories successfully mapped in Ohio were: (1) stripped earth, (2) partially reclaimed earth, (3) vegetation, (4) shallow water and (5) deep water. These same techniques were used successfully in mapping land water cover in water basins of the coal mining region of eastern Tennessee for the U.S. Geological Survey. Map production costs were estimated to be about \$ 0.50 per square mile at 1:250,000 scale to \$7.00 per square mile for 1:24,000 scale. It was estimated that when mapping larger areas (750,000 square miles) costs could be lowered to \$0.30 per square mile per 1:250,000 scale maps. Accuracies better than 90% in most categories of mapping were reported in this study. The final report of this 2 1/2 year NASA-supported study was issued in February 1975.

From a review of the literature, one of the most comprehensive research efforts to date on the overall application of remote sensing data (Landsat, Skylab and aircraft imagery) to environmental problems relating to coal mining (Amato, et al, 1975) was done in the eastern Appalachian coalfields and anthracite areas of Pennsylvania. The researchers conclude that at present for year-round monitoring of surface mining, Landsat imagery is of limited value. However, the authors feel it may be quite useful for annual updates, if appropriate baseline data is available. They also concluded that better resolution as provided by the Skylab imagery offers greater potential for routine monitoring and that aerial photography can provide data for all types of surface mining activities. Obviously, the expected better resolution (30m) of Landsat follow-on would be very desirable. Tables are presented with the authors' assessments of the usefulness of various types of remote sensors to detect mine subsidence and to effectively identify selected mined-land features.

In one of the most recent Landsat remote sensing surface mining efforts (Anderson, et al, 1975) NASA researcher A. T. Anderson and his colleagues demonstrate that Landsat computer processed data can be used to identify, classify and measure the effects of strip-mining. The study was a cooperative effort among NASA, the Maryland Bureau of Mines and General Electric's Space Division. Overall average accuracies of measuring strip mine affected acreages were 93%. The studies have provided the state of Maryland with baseline data and an additional tool for rapidly monitoring the progress of back-filled, planted and reclaimed areas to minimize environmental damage. Turning to coal surface mining development in the western United States, Denver-based EPA researchers (EPA, 1975) investigated the application of Landsat technology to evaluating strip mining of coal and associated reclamation in the Northern Great Plains (Wyoming, Montana, North and South Dakota), which contain nearly half of the total U.S. coal resources. Out of an original thirty mines considered, computer classification was successful at fourteen. The mine areas were divided into: (1) active mining areas, (2) graded spoil piles, (3) ungraded spoil piles, and (4) vegetated spoil areas. The land classification and overall determination was most successful for large mines. Some problems were encountered in barren parts of Montana and Nevada

distinguishing areas disturbed by mining activities from adjacent lands not disturbed by mining. Baseline data developed in this study would prove useful to monitor changes if future western coal developments take place as anticipated.

One of the most recent (March 1976) remote sensing projects in surface mining monitoring using Landsat data has been started in the Kaolin mining area of Aiken County, South Carolina. The state implemented surface mining regulations on January 1, 1975. In preparation for developing monitoring procedures, aerial photos were taken over all surface operations in June 1974. A joint pilot project was started to determine the usefulness of Landsat imagery as a monitoring tool. The EROS Program (USGS), the U.S. Bureau of Mines State Liaison Officer,and the South Carolina Land Resources Commission cooperated in this work. Computer compatible tapes were obtained of repetitive Landsat scenes over Aiken County comparing 1974 and 1975 mining progress. In early March 1976, this digital data was analyzed at the EROS Data Center, Sioux Falls, South Dakota, and compared with the planimetered areas from the aerial photos. The initial tests were highly encouraging with correlations of over 99% obtained in a number of cases. Further research will be conducted at the EROS Center which could lead to operational use of Landsat information.

A general conclusion can be reached that Landsat data <u>could</u> be a useful tool in providing monitoring and surface classification information to state and federal regulatory agencies. Its potential usefulness has been indicated in a series of demonstration and research projects. However, the gap between potential users and research projects is a formidable one. One factor that deters users is the high cost of the computer capability to use digital data. State legislators are not likely to provide funds which will enable state agencies to use Landsat data unless operational benefits and savings are indicated. This technology transfer gap is one of critical importance and NASA and EROS/USGS/USDI and other federal user agencies (EPA/USDA/NOAA) should increase their efforts with state agencies who are potential users. For the present this need of concentrating on the educational task of literally leading potential users by the hand until convinced of satellite imagery's usefulness as another operating tool in monitoring and mapping surface mining overshadows any considerations of concern over Landsat follow-on improved characteristics.

TABLE II-6
APPLICATION ASSESSMENT TABLE

Application:

Mined Land Inventory

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Mining		
Disturbed areas.	Areal extent change monitoring.	For measuring large mines (100 acres +) -- very good. Less effective for smaller mines. Very effective for change monitoring.	11:00 am crossing will improve capability in this application because of better reflectivity. Finer resolution is a big plus.
Water impoundments.	Areal extent sedimentation.	Totally effective for measuring area. Very good for monitoring sediment-trapping effectiveness.	
Spoil piles (refuse).	Measure area, classify types and distinguish from bare rock of mined area.	Effective for measuring areas of large mines, less effective for small mines and for classifying areas within mines.	Finer resolution should help considerably; increased number of grey levels should help with classification.
Type of mining and status.	Areas vs. contour mines; active vs. inactive mines.	Complete accuracy for area vs. contour mine distinction; ability to discriminate active from inactive less certain.	Ability to distinguish active operations would depend on visibility of equipment, which in turn would depend on contrast, since most items of equipment are below size discrimination minima.
Access and haul roads.	Position location and associated erosion.	Complete accuracy on road location, probably good discrimination of sedimentation below roads, erosional effects probably too small scale to pick up.	
	Reclamation		
Percent vegetative cover.	Amount of area revegetated. Success of revegetation.	Probably successful in east where contrast is strong, less certain in west where contrast between mined and unmined areas is slight.	Repetitive coverage very important on seasonal or annual basis in order to be sure of having appropriate baseline data for monitoring change; infrared should be very valuable in monitoring success of revegetation.
Surface roughness.	Distinguish graded from ungraded spoil.	Easily done in large area mines, more difficult to impossible for small or contour mines.	Radar would be very valuable for this application.
Vegetation types.	Distinguish between grass and shrubs vs. trees.	Probably could be done.	
Surface spoil types.	Distinguish between acid-producing shales (dark) and inert material (light); also between finely divided material (topsoil) and large rock fragments.	Possibly could be done if there is enough tonal contrast between dark and light rocks. Topsoil probably could be distinguished from rock fragments on basis of brightness.	Radar might help with topsoil-rock differentiation if wavelength is small enough; increased number of grey bands should permit finer discriminations.

TABLE II-6
APPLICATION ASSESSMENT TABLE (Contd.)

Application:

Mined Land Inventory (Cont'd)

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Environmental Features		
Erosion/sedimentation.	Detect areas that erode badly in heavy rain as well as areas that are easily erodible in general; detect siltation in streams and lakes.	Nine-day coverage should make it possible to eventually catch most areas. In general sedimentation much better shown than erosion.	
Acid mine drainage.	Detect vegetation damaged by acid.	IR band can detect this very well; problems arise in west where vegetation is sparse.	
Mine subsidence.	Detect cracks and/or depressed areas.	Landsat probably not capable as presently set up.	Fine resolution radar might help with this.
Landslides.	Determine location and area of potential landslide hazards.	Could be done in areas of strip mine spoil, probably not in vegetated areas of natural colluvium.	Slope angle measurements are needed; laser profiling radar might help.

The improved resolution of the Landsat follow-on Thematic Mapper will be helpful, but surface mining and reclamation regulatory users need to be introduced first to the existing systems to determine their usefulness, prior to considering more sophisticated systems, which may or may not be required.

4. Summary

In summary, there is presently no operational use of Landsat data by state or federal agencies in monitoring surface mining activities and their impact on the environment. Despite possible cost benefits to potential users, use of Landsat data requires too many institutional changes. As summarized so aptly in the Amato (Amato, et al, 1975) paper, "....Integration of remote sensing monitoring systems into the state mining regulatory programs depends upon many factors that differ substantially from place to place due to state requirements and the environment.... a real question still exists, however, as to what extent analysis of satellite imagery would replace or supplement current monitoring procedures and what the real cost saving would be."

If more emphasis were placed on the "technology transfer" aspect of remote sensing, excellent possibilities exist for many operational uses of satellite imagery in surface mining regulatory functions.

H. URBAN LAND INVENTORY

1. Introduction

Urban land use in a modern industrial state unquestionably extracts a greater toll from the land, the air, and the life forms (human and otherwise) than any other form of existence that man has devised for himself. When one considers that over 76 percent of the population of the United States resides in 276 metropolitan clusters whose total territory encompasses less than 2 percent of the nation's land area, the impact is all too apparent. In selected small areas, the residential population densities exceed 250,000 persons per square mile. The direct and secondary effects of these living conditions have a demonstrable effect on both the physiological and psychological well-being of humans.

As a result of the better understanding of these effects and the increasing scarcity of the resources of urban life as it has developed,

it is rapidly becoming necessary to understand and measure the complex social, economic and geographic interrelationships of the metropolis. Of necessity, most of this work must be done by microanalysis. Even with the most powerful computers, this analytic approach cannot process and classify the data in a timely manner. The use of remote sensing, with the level of capability incorporated in the Landsat follow-on program offers some hope to slicing the Gordian knot of monitoring the dynamics of metropolitan life.

The report which follows is divided into two major sections: (1) diversity of users and their program requirements; and (2) potential applications of Landsat and Landsat follow-on system.

The primary study goal was to evalute the Landsat follow-on program from the viewpoint of the urban user. The information provided will eventually allow decision-makers to address such questions as -- should the mission be flown?; What should it have on board?; In what form should the output be produced?; and How will the data be used?

The panel concludes that, contingent upon the inclusion of an aircraft capability, information transfer systems, and institutional arrangements permitting direct user specifications, Landsat and Landsat follow-on can have major impacts on the supply of data for urban and metropolitan regions. Data must be supplied with associated geographic referencing to enable tie-in with users' existing information systems.

2. Diversity of Users and Their Program Requirements

It was found that the urban data analyst requires different levels of resolution and types of products, depending upon their interests and/or programmatic requirements. The following pages summarize the diversity of users and the geographic levels of interest exhibited by the users.

Characteristics of the Data Users

Typically, the user of such data will be an institution already established, with some responsibility for planning, managing, or zoning, present or future uses of the land and water resources. Examples of such users in the public sector are local planning departments, agencies responsible for coordinating and drawing up region-wide land use plans (such as regional councils of government), state planning departments, state resource management or environmental departments, and numerous

federal agencies having roles ranging from direct planning and management on federally-owned lands to administration of programs through which funds are transferred to state or local agencies for implementation of various data-gathering or planning functions. Corporate and educational institution users are more difficult to categorize. However, they do exist and there is a potential for the number of companies and schools to increase.

The analyses performed by these user agencies and firms are transferred to state or local agencies for implementation of various data-gathering or planning functions. These user agencies and firms vary greatly in budgets, skilled staff, data processing equipment, and sophistication in obtaining, handling, and making use of land use and related environmental data. However, the user institution typically has some sort of information system for dealing with data of the type described. Some such information systems are highly advanced, making use of modern spatial data-handling equipment and procedures, including large digital computers linked to forecasting and other modeling capabilities.

Examples of users' requirements presented here include those of a local governmental body (City of Los Angeles) and those of several federal agency programs which have major implications for data of the type which could be supplied by remote sensing systems. Most users' requirements can be conveniently grouped under three spatial hierarchical levels: the land parcel (smallest); the census tract (intermediate); and the metropolitan region (largest).

. Parcel Block Level Information System

The City of Los Angeles has developed a parcel level information system -- Land Use Planning and Management System (LUPAMS). The basic records for this system are the 700,000 individual land ownership parcels collected by the Los Angeles County Assessor as part of his property assessment activities.

Geo-BEDS and LUMIS are both block level geographical information reporting systems referencing data reported as units or percent of units for each individual city block. Geo-BEDS stands for Geographically Based Environmental Data System, and LUMIS stands for Land Use Management Information System. The city blocks used in both systems are those that

were identified and assigned individual numbers (geo-codes) by the U.S. Bureau of the Census, for the 1970 census.

. Census Tract Level Information System

The Scientific Urban Matrix (SUM) was developed by the Los Angeles Community Analysis Bureau (CAB) and utilizes the census tract as its geographic reporting unit. The basic charge of the CAB was to define, identify and locate urban blight in Los Angeles. To that end they produced the first operating automated geographical reporting system. That system consisted of records for the 741 census tracts in the City and contained over 300 data items, collected through a variety of procedures for each tract.

. Metropolitan Level Information System

Many studies in the metropolitan environment, of necessity, require an analysis of a large proportion of the entire area. For instance, drainage or watershed studies or, alternatively, transportation studies require that a large area be viewed as a whole within the larger metro context. Sometimes, these studies can be derived from small area data by aggregating upward. However, the level of detail of the data need not be as fine as is usually collected at a tract or block level. Consequently, much of the required data often can be derived from space imagery at a suitable detail level.

An example of this approach is the land use classifications for traffic zones in St. Tammany Parish, Louisiana (St. Tammany Parish, land-use report summary, Regional Planning Commission, New Orleans, Louisiana). Landsat data was classified into 15 classes and aggregated by traffic zones.

. How Present Data Needs Are Being Met (or Falling Short)

At present the users of urban area remote sensor data obtain these data from a wide variety of sources. Heavy reliance is placed on standard sources of aerial photos, such as the U.S. Department of Agriculture photography, or USGS photography taken in support of topographic and orthophotoquad mapping programs, and is available on an operational basis for purchase by users. More recently, aerial photography, space photography, and multispectral scanner imagery from space has been available from the NASA earth observation program's aircraft and satellites; data is distributed to users by the EROS Data Center of the Department

of the Interior, in Sioux Falls, South Dakota. Where coverage from these sources is not adequate, and where data needs are urgent, special arrangements for obtaining aerial photo or remote sensing data coverage must be made. These generally involve services performed by private contractors, or in some cases, government agencies who cooperate with local groups working on environmental and mapping projects in certain regions.

The single most prominent characteristic of the present system for supplying remote sensing data is the lack of coordination and direction at the federal level. Workers who are familiar with various agency sources learn where and when certain regions are likely to be flown. A potential user who is new to the field, however, would have a much harder time locating photography that is available. To serve such users, a number of state and federal agencies have attempted to provide summary information, but there is no uniformity in the availability of such information.

. Implications of Federal Legislation Requirements for Data

A representative listing of existing federal programs is found below:

1. The USGS National Land Use and Data Analysis Program
2. Federal Housing Act of 1954, as amended
3. National Environmental Policy Act, 1969
4. Coastal Zone Management Act of 1972
5. Federal Water Pollution Control Act of 1972
6. National Flood Insurance Act of 1968
7. Periodic population updates and estimates required by federal legislation

All of the above are present requirements impacting heavily on many or most of the metropolitan areas of the country. Since these acts are all in force at the present time, the need for information to be supplied in support of these legislative programs is immediate. Experience in a metropolitan area test site indicates that imagery from Landsat 1, and better yet, data derivable directly from computer compatible tapes from Landsat 1 and 2, are useful for providing some of the required information

under these programs. In all cases, however, much of the information required is more detailed than that available from Landsat, and would call for the use of aircraft data beginning immediately. Whether the private sector on an ad hoc contracting basis can provide this coverage in as orderly and cost-effective basis as can the principal federal involved in the same type of work is a question not addressed by this report. It is clear, however, that whatever source is drawn upon to obtain the basic remote sensing data, much greater coordination than exists at present is needed to assure conservation of the taxpayers' dollars which go into this program. For most of these programs, this information is needed now. These users cannot wait for Landsat follow-on in the post-1980 period to plan for data delivery.

. Urban Studies Using Landsat Data

--METROPOLITAN/REGIONAL INFORMATION SYSTEMS

- An interactive Land Use Mangement Information System (LUMIS) using, in part, Landsat and high-altitude images has been demonstrated in Los Angeles, California, and Tacoma, Washington. Software for the LUMIS System has been transferred to both cities.

- An information system has been developed at NASA-JPL which extends the capability of present systems by using digital image processing techniques to directly incorporate Landsat digital data, thereby permitting the user to detect changes and perform resource inventory rapidly. This system is known as MILUS (Multiple Input Land Use System).

- General urban categories (commercial/industrial, residential, extractive/barren, open space, major transportation, etc.) have been classified using Landsat digital data to accuracies over 80% -- by keeping urban classes broad, reasonable classifications accuracies can be obtained.

- Urban change detection using Landsat digital data has been demonstrated at reasonable confidence levels -- approximately 90%.

- Using Landsat digital data, urban boundary delineations can be made -- 75% accuracy achieved in S. E. Washington, D.C. area.

- Developed procedures to document land use change by census tract.
- Interfaced census urban atlas file delineating tract boundaries with Landsat digital imagery, using the MILUS system.

One of the conditions necessary for realizing urban applications is the incorporation of the development of a total geographically based information system as part of its Landsat follow-on activities. Such a system must be developed if the Landsat project's data is to be widely utilized by urban planners and decision makers, who as yet, have not been able to use Landsat products in the direct service of the majority of the nation's population. Current Landsat data products have not been used by non-aerospace professionals in the area of urban planning because those products have been limited to raw photographic or image-based data and even that data has been of questionable quality. The cost of converting those materials to useful information is still too high for local governments or entrepreneurs to assume. What are needed are land use maps and other products produced from satellite imagery that also show traditional political or statistical boundary overlays (i.e., census tracts or city limits) along with data tabulations for these areas.

Meeting those requirements will mean that the federal government must recognize the interdependence of NASA, USGS, and Census when it comes to providing a truly effective and integrated geographical information system. Until this agency integration takes place to produce an effective information system, satellite imagery will not take its rightful place as a major source of land use information for urban areas.

Another condition necessary for fulfilling the data needs of the diverse users in the urban community is a communication and coordinating mechanism for enabling the data producing systems to be truly responsive to the priority needs of the users. Data producing systems would include aircraft data as well as Landsat. Since no single user will likely be able to afford a large remote sensor data collection program, coordination among users will be as necessary as user-producer coordination. Also, to avoid duplication or its opposite, the omission of needed coverages, coordination among data producer agencies will also be required. This requirement for data producing systems to be responsive to actual users' needs has perhaps best been expressed by former NASA Associate Administrator, Dr. Robert C. Seamans, Jr., who states:

"There exists, at present, no institutional mechanism which permits the large body of potential users -- which the Board sees as existing in state and local governments, in a business community, and in educational institutions -- to express their needs and to have a voice in matters leading to the definition of new systems. To date, it is the providers of space systems who devise what they believe are useful requirements and proceed to build experimental systems. They then find themselves in the position of trying to 'sell' this technology to prospective users. This process needs to be reversed. The Board perceives a need for some organizational mechanisms designed to assure user participation in defining the system."

(Source: Pacific Northwest Land Resources Inventory Demonstration Project: Project Summary Document, 1975.)

3. Potential Applications of Landsat and Landsat follow-on System

. Conditions for realizing Landsat potential

The panel believes that Landsat and Landsat follow-on systems can have a significant and possibly revolutionary impact on the supply of data for planning, managing, and monitoring urban and metropolitan regions. For users in urban and metropolitan areas, and regions under the influence of urbanization, remote sensing/ land use data requirements are enormous and they are immediate.

Realization of the potential of the Landsat systems, however, is contingent upon the realization of certain technological and institutional conditions which derive from the diverse and dispersed nature of the users as mentioned in the previous section. With a strengthening of cooperative ties among data user and producer institutions, arrangements could be set up beginning immediately, which from the user's point of view could be treated as an operational system, capable of responding to data needs in accordance with regional and national priorities.

The conditions required for bringing about these results are the following:

(1) Data would be provided with geographically coded reference and associated software which would enable direct tie-in with users' geographic information systems.

(2) Management of delivery of data derived from both Landsat and aircraft would be combined and coordinated regionally, with user priorities determining the specifications of remote sensor/land use data requirements.

(3) Present trends toward coordination and cooperation among data users and data producers would continue and be strengthened, in 3 stages: user-user combinations; user-producer communication; and producer-producer collaboration on data collection and processing.

. Applications of an "operational" system

The need to achieve data delivery to users as quickly as possible must be stressed, while at the same time permitting the broadest possible contribution from NASA efforts that are still defined as "research and development." Perhaps a reasonable compromise would be for NASA to consider the first five years of a massive data delivery program to users (beginning in 1976) to be a phase of a longer-term research and development program.

Three levels of a geographic hierarchy of areas or "building blocks" are defined for categorizing the land use/land cover data: the ownership parcel, the census tract, and the metropolitan region. We strongly recommend that the coordination and delivery of data satisfying users' needs at all three levels be kept together in a single program, rather than separating these data on the basis of which will be supplied by aircraft and which by Landsat. Keeping the three levels together in a single coordinated effort will have two important benefits: it will allow realization of economies through minimizing collecting of duplicative or overlapping data sets, and it will keep the users whose requirements can at present only be satisfied by aircraft data in close touch with advances in satellite capability, thereby increasing the likelihood that these users may move toward future utilization of Landsat follow-on.

The users endorse the specifications that are being proposed for the Landsat follow-on sensor platform, especially the presence of the thermal sensors and the increased number of gray levels. These latter two specifications have great potential for discriminating the complex patterns within the urban setting. The increased levels of spatial resolution will be needed by some urban applications; however, even the 80 meter resolution currently offered has not been effectively used, primarily because of data processing and data management limitations.

It is strongly suggested that more consideration be given to the ability of the users to effectively use all of the data that will be available through NASA's support for the development of geographic data management system that is matched to the level of sophistication of the sensors.

In almost every situation in the urban setting, the primary source of data is not remotely sensed data. This will continue to be the case. However, the costs (real and social) of data acquisition make it imperative that the urban analysts use remotely sensed data to monitor the "aging" of his primary data between complete censuses or acquisition of new primary data. Remote sensing will both reduce the cost of primary data collection (by allowing the analyst to use "spot surveys" only where the primary data has aged beyond some level as indicated by remotely sensed techniques),or by allowing most of the primary data (which generally is difficult and costly to obtain and integrate into an urban data system) to be used over a longer period of time before a complete reacquisition process must be undertaken.

All of these benefits are dependent upon the existence of a software system (a geographic data management system) which will allow a quick and relatively inexpensive means of integrating Landsat data into and evaluating it against the users' primary sources of data, whatever their nature and level of geographic specificity.

Several steps would be required to implement a group of user requests. The first would be to assemble combinations of users to determine commonality among data needs for users in geographic proximity with each other. Next would be establishment of priorities

to be assigned by appropriate referee groups to the assemblage of user requirements logically combinable in space and time. Then would come translation, by technical experts of user requirements into sensor system specifications. Approximate ground resolution requirements would be determined by some devices similar to the charts shown in Figures II-1 and II-2 which are included here to illustrate approximations rather than exact engineering measures. The most obvious initial conclusion to be drawn from examining Figures II-1 and II-2 is that aircraft data will be required to satisfy data needs at the parcel level. Landsat and Landsat follow-on could supply some of the data needs for tract level and metropolitan level requirements.

Finally, coordination among data producer agencies will be necessary to assure that the nation's capabilities in this area are applied to the highest priority user needs. While some requirements can be satisfied by the publication of standard products, such as lists and maps of land uses by census tracts for metropolitan areas, other requirements may have to be accommodated on an ad hoc basis as the need arises. Remote sensing systems have the technical capability to respond flexibly to such requests; archives of tapes and images should be made easily available to handle such ad hoc requests.

Following is a partial list of applications of the Landsat and Landsat follow-on system, as defined here incorporating aircraft data, aimed particularly at urban and metropolitan area users.

Applications requiring parcel or block level data

- Environmental impact statements
- Inventory and monitoring under flood insurance program
- Monitoring conformances to zoning regulations
- Some housing quality assessments
- Transportation stock and storage assessments
- Industrial and recreational site surveys
- Education and research applications

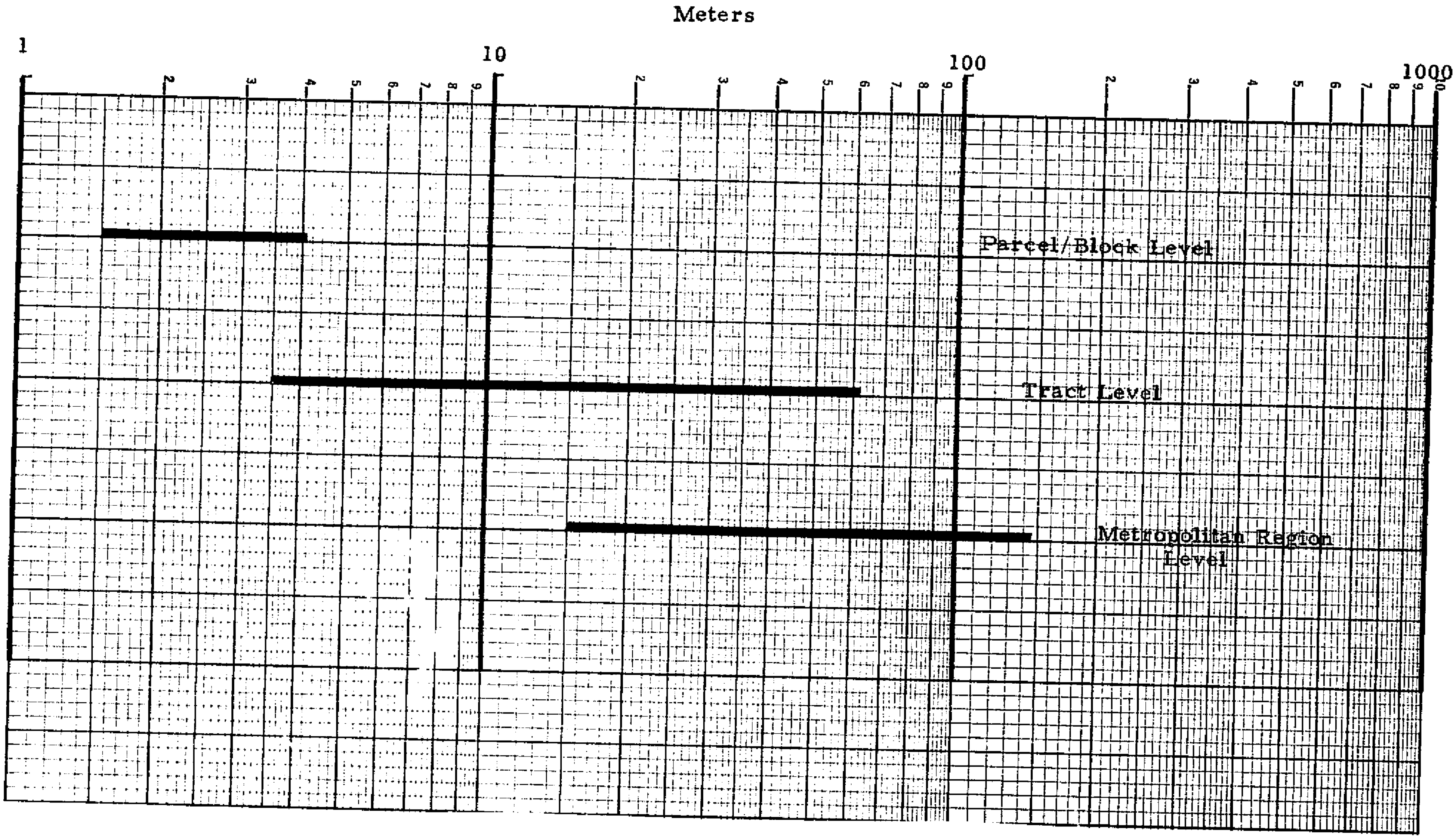

Figure II-1. Approximate Ground Resolution Required for Identification of Key Land Use Features for Three Levels of the Geographic Hierarchy of Needs for Urban Area Remote Sensing Data.

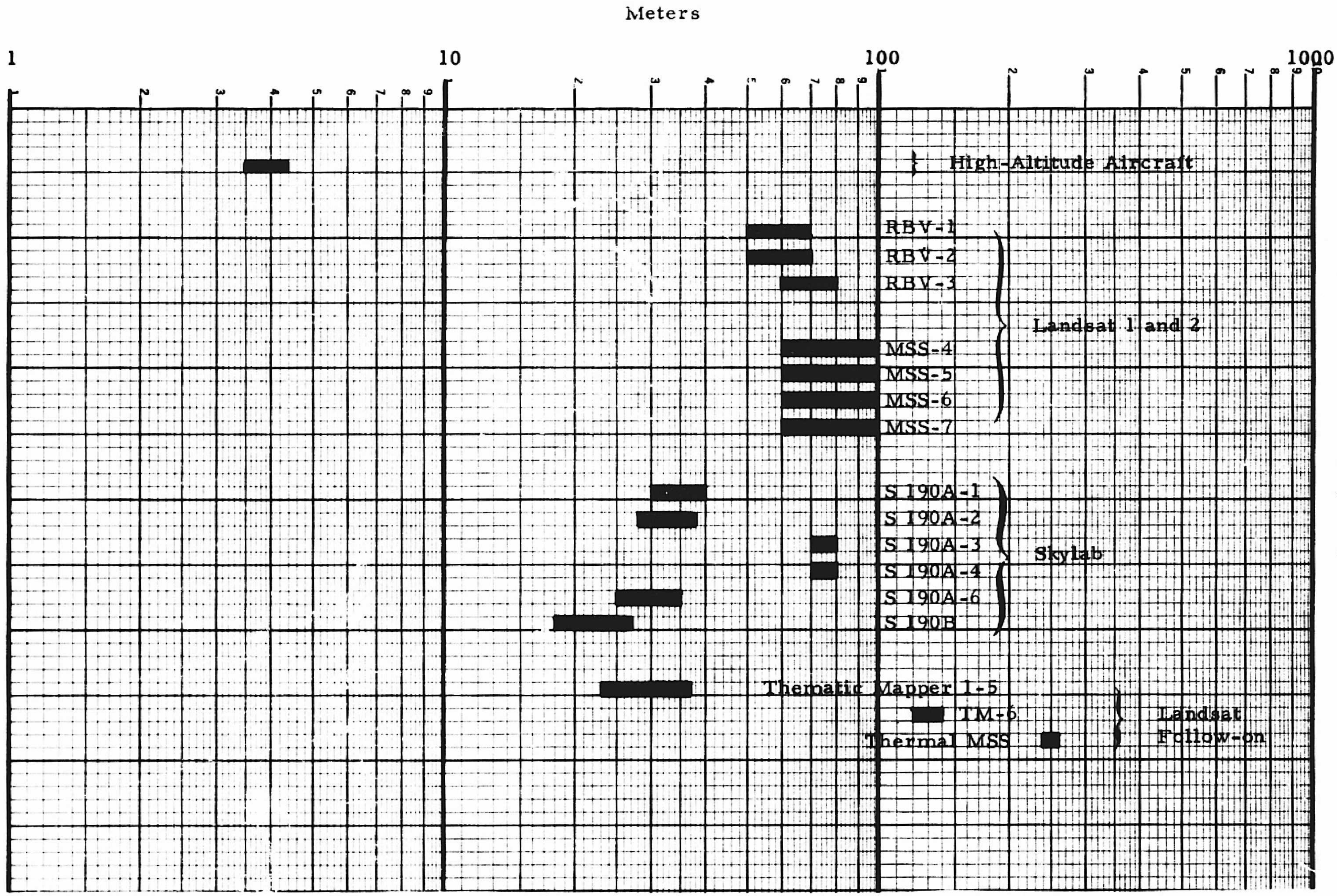

Figure II-2. Approximate Ground Resolution of Various Sensor Systems Critical to Users' Identification of Key Land Use Features.

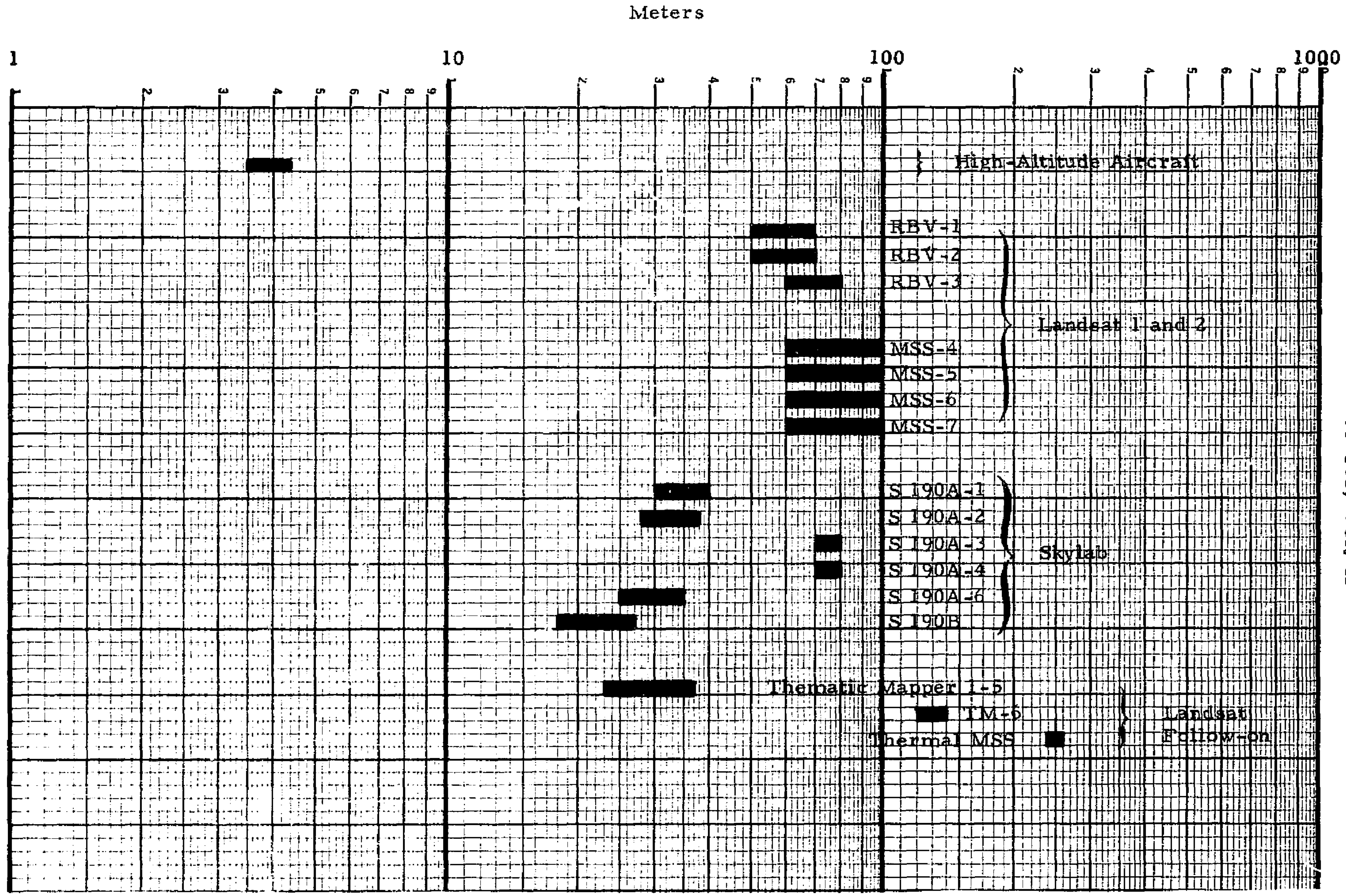

Figure II-2. Approximate Ground Resolution of Various Sensor Systems Critical to Users' Identification of Key Land Use Features.

Applications requiring tract-level data

- Land use inventory legal requirements and local planning applications
- Population and housing estimates
- USGS Land Use Data and Analysis Program
- Transportation and traffic generation studies
- Hydrologic factor estimates
- Climatological and urban heat island assessments

Applications requiring metropolitan level data

- Urbanized area delineation
- Surface temperature distribution for urban heat island assessments
- Reconnaissance for site location overview (e.g., shopping centers, residential subdivisions, major industries)
- Education
- Regional hydrology studies

4. Summary

This section has presented several examples of the importance of land use data in planning activities.

The section strongly recommends that for urban users NASA focus on constructing an information delivery system as well as on increased technical development of satellites. The delivery system should allow derivation of: (1) a set of tabulations for small area data items as units of area (e.g., hectares or acres) acres per census tract, (2) a map of land use patterns with census tract boundaries overlayed, and (3) with increased imagery resolution, an interactive information system that will allow satellite data to be used at the neighborhood or block level.

There is no doubt that land use data is one of, if not the most, critical information key to understanding urban morphology and change. No national means of collecting uniform (scale, time, category) urban geographical information now exists. All inter- and intra-urban decisions regarding land use are currently largely made to some degree by the "seat-of-the-pants". Landsat follow-on will provide the capability of coming closer to fully understanding cities than ever before.

I. LANDSAT DATA DELIVERY SYSTEMS

1. Background

From the earliest beginning of the Landsat (formerly ERTS) program, efficient distribution of data to all users has been a firm program objective. The cooperative program with the EROS Data Center (EDC) was established for just this purpose. In the early stages of the program, however, much frustration was caused by start-up and other problems. These unavoidable problems are apparently still causing many potential users to hesitate before making a significant commitment to operational use of the data.

Prominent among the early problems were long delay times in getting data to non-NASA-funded users and failure of the public to understand the research orientation of the Landsat program. While NASA obviously could not have avoided these problems altogether, NASA is still seen by some users as "failing to deliver" on their promises for the satellite data. In short, many users and potential users were severely disappointed by the lack of timely data delivery. For some, but by no means all users, delivery of timely data was critical to their use of the data, and, therefore, they dismissed Landsat data as a viable input to their decision-making.

The above is history and of relatively little importance here except to document the trends in data delivery and user interaction with NASA's Landsat program. The remainder of this section will be devoted to a discussion of the present data delivery system and suggestions for improving the data delivery system proposed for Landsat C and Landsat follow-on.

2. Present Data Delivery System

The present system for providing Landsat data to users is as follows: Landsat data are received by a ground receiving station and shipped via surface transportation to GSFC (if not received by the GSFC station). These data are then recorded on an archival high density digital tape (HDDT). The HDDT data are further processed to provide two products: a master film image and reproduction masters from which all other film images are produced. These reproduction masters are forwarded to EDC for preparing images to be sold to users. At the present time, HDDT data are not routinely converted to CCTs and forwarded to EDC.

CCTs are typically produced on request. The process is initiated when EDC receives an order for a scene on CCTs. The request is forwarded to GSFC where the appropriate archival HDDT is secured. Data are then reformatted onto CCTs and copies of the tapes are mailed to EDC. The EROS Data Center then copies a tape for the customer and forwards it to him.

The complete process of receiving a data request, producing the product, and delivering the requested data to a customer typically takes from two to three weeks for film products. For digital data, the process is considerably longer and generally requires from one to two months. These delays are unacceptable to a major fraction of users and potential users. The TERSSE study found that approximately 37% of federal requirements for Landsat data could only be met with data delivery times of one week or less. Sixty-one percent of the federal requirements called for data delivery in one month or less. Data delivery needs of the non-federal public agencies and the private sector concentrated in the one week or under category.

Based on the above, it can be seen that many potential users are effectively denied access to the Landsat system since the data delivery schedules do not meet with their operational requirements. This serious problem has not gone unnoticed, and substantial improvements in data delivery are planned for inauguration at about the time Landsat C is launched.

3. Improved Data Delivery System

A vastly improved data delivery system is proposed for initiation in about two years. The new system will consist of satellite communications data links to expedite delivery of the data to users as well as additional processing to provide better digital and photographic products. Although plans are not firm at the moment, the basics of the new system will be discussed below. While the discussion is primarily limited to digital data delivery, most of the same comments also apply to photographic products.

Improvements in Landsat data delivery include:

1) Collection of the data from the Landsat satellite itself via the Tracking and Data Relay Satellite System (TDRSS)

2) Relay of the Landsat data to the TDRSS ground receiving station

3) Retransmission of Landsat data to GSFC via a domestic communications satellite (Domsat)

4) Initial processing of Landsat data at GSFC to provide annotation data, system corrections, approximate geographical reference data, etc.

5) Transmission of "cleaned-up" raw Landsat data to EDC via Domsat

6) Rapid screening of Landsat data at EDC to determine those scenes which should receive additional processing, and preparation of archival copies of high density digital tapes (HDDT).

7) Preparation for users, on demand, of CCTs which have been geometrically corrected and/or contain special processing features such as a specific map projection.

The above procedures are estimated to cut data delivery time (from acquisition to delivery to users) to 2-4 days. Obviously, this is a tremendous improvement over the current data delivery schedule. However, it still fails to satisfy the users who want data within one day of its acquisition. Also, depending on the exact nature of the customization provided by EROS Data Center, it may or may not serve the user's needs.

For example, a problem which is discussed in more detail under the management and information systems topic concerns geometric corrections to the data. To include Landsat data in a natural resources information system, along with other data inputs, the Landsat data must be corrected for geometric distortions and accurately located with respect to the coordinate system used in the information system. Furthermore, it is very useful, but not essential that the data be rotated to provide a N-S orientation. An alternative data delivery system for Landsat follow-on which should meet the needs of a large fraction of potential users is described in the next section.

4. Alternative Data Delivery System for Landsat follow-on

The data delivery system described in this section closely parallels that described in the previous sections. However, there are important differences which make the data delivery system more responsive to user needs. The proposed alternative system is the same as that described previously through receipt of the Landsat data at GSFC. However, significant differences begin to appear not only in the types of processing provided, but also in the functional roles played by GSFC and EDC.

The following changes in the data delivery are proposed for consideration:

1) Processing of data at GSFC to provide all necessary geometric corrections

2) Reformatting (rotation) of data to provide N-S pixels

3) Precise registration of data to a preselected map projection using ground control points if necessary

4) Transmission of the above data to EDC via Domsat one band at a time instead of with bands interleaved

5) Transmission of raw Landsat data to EDC via Domsat or mail with only annotations added.

There are substantial advantages to the above procedure to justify procedural changes to accommodate the revisions. First, steps 1-3 above are very expensive preprocessing tasks that users must perform if they

are to accurately register Landsat data to other data in a natural resources information system, for example. Performing these functions at GSFC to a standard map projection and to a known accuracy will help to standardize the nature of natural resources information systems -- at least with respect to the land cover component. Futhermore, for those users whose data needs cannot wait an additional 2-3 days to get data from EDC, transmission of data band-by-band will enable direct reception from the Domsat at minimum costs -- provided these users are willing to make the additional investment in processing equipment.

Providing a standardized, corrected format for Landsat data is properly a part of data delivery to users. While it is true that many users have been providing their own geometric corrections, the present effort is extremely fragmented. Furthermore, it is probable that the same corrections have been applied to a scene by multiple users -- unaware that corrected data already exist. This is a wasteful utilization of resources which could more properly be applied elsewhere. With the increase in the number and scope of natural resource information systems, the need for standardization at the earliest possible point in the data delivery system becomes more evident.

By its very nature, however, a standardized data format will not satisfy all users. Customization of data products would take place at EDC, using the raw Landsat data with only the annotations added. Providing these custom products from EDC would tend to increase the efficiency of data distribution to all users since delivery of standard products by EDC would require little more than copying the data tapes. Customizing the data products, however, would likely require additional time and effort which might severely delay delivery of these products if they had to compete with the standard processing for analysis time.

The proposed alternative to the data delivery system will require some reconsideration of the Landsat follow-on mission operational parameters. The current series of Landsat satellites has conclusively demonstrated the superiority of digital data products for most purposes. The use of digital data is likely to continue to predominate as should the trend toward inclusion of Landsat data in natural resources information systems. Therefore, it is worthwhile to give additional serious consideration to <u>user-oriented</u> data delivery systems.

TABLE II-7

Requirements Assessment Table

3 = Essential 2 = Very Valuable 1 = Desirable 0 = Inconsequential	Digital Format	Image Format	Regional Image Coverage = 50 mi/side	Stereo	High Resolution	Visible/Near IR	Thermal Bands	Rapid Cycle	Seasonal Coverage	Rectilinear Presentation	
Natural Resources Inventory	3	3	3	2	2	3	3	3	3	1	
Wetland Inventory and Mapping	3	1	0	1	2	3	1	2	3	-	
Coastal Zone and Shoreline Mapping and Inventory	2	3	2	1	2	3	2	1	2	2	
Urban Land Inventory	3	2	1	0	3	3	2	0	2	0	

APPENDIX A

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APPENDIX B

ACRONYMS

ADP	Automatic Data Processing
ASG	Applications Survey Group
B/W	Black and white (film)
CAAT	Computer-Aided Analysis Techniques
CAB	Community Analysis Bureau
CCT	Computer Compatible Tape
CIR	Color Infrared (film)
DMAAC	Defense Mapping Agency Aerospace Center
DMAHC	Defense Mapping Agency Hydrographic Center
Domsat	Domestic Communications Satellite
DT	Direct Transmission
EDC	EROS Data Center
EPA	Environmental Protection Agency
ERIM	Environmental Research Institute of Michigan
ERL	Environmental Research Laboratories
EROS	Earth Resources Observation Satellite
ERS	Economic Research Service
ERTS	Earth Resources Technology Satellite
FOV	Field of View
FWS	Filter Wedge Spectrometer
Geo-BEDS	Geographically Based Environmental Data System
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HDDT	High Density Digital Tape
HUD	Housing and Urban Development
IFOV	Instantaneous Field of View
IR	Infrared
JPL	Jet Propulsion Laboratory
L-1	Landsat 1
L-2	Landsat 2
L-C	Landsat C
L-Fo	Landsat follow-on

LARS	Laboratory for Applications of Remote Sensing, Purdue University
LST	Large Space Telescope
LUDA	Land Use Data Analysis
LUMIS	Land Use Management Information System
LUPAMS	Land Use Planning and Management System
MESA	Marine Ecosystems Analysis
MILUS	Multiple Input Land Use System
MMU	Minimum Mapping Unit
MSS	Multi-Spectral Scanner
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NESS	National Environmental Satellite System
NMAS	National Map Accuracy Standard
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetland Inventory
ORSER	Office of Remote Sensing of Earth Resources, Pennsylvania State University
RBV	Return Beam Vidicon
SCS	Soil Conservation Service
SOM	Space Oblique Mercator
SUM	Scientific Urban Matrix
TDRSS	Tracking and Data Relay Satellite System
TERSSE	Total Earth Resources System for the Shuttle Era
TM	Thematic Mapper
USDA	U. S. Department of Agriculture
USDI	U. S. Department of Interior
USGS	U. S. Geological Survey
UTM	Universal Transverse Mercator (map coordinates)

APPENDIX C

RESUMES

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Albert Landini is a City Planner charged with developing urban information systems for the Los Angeles Department of City Planning. He holds a B.A. and a M.A. degree in Urban Geography from California State University at Los Angeles and a M.P.A. in Research Administration from the University of Southern California. His doctoral work is in the area of Program Evaluation at UCLA. Mr. Landini has been active in designing and implementing DIME, aerial photo, and parcel based information systems for planning agencies and community colleges.

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Have worked with the State Geological Survey of Tennessee for 25 years, plus short stint with TVA; have also served as an instructor in Geology with the University of Tennessee, Nashville Branch. Professional work has been primarily in area/geologic mapping, but with an almost equal emphasis on coal geology and coal resources assessment. Am presently principal assistant to the Director of the Tennessee Division of Geology in charge of the Division's geologic mapping and coal resources programs.

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Formerly Director, Marine Resource Applications, Earth Satellite Corporation. At Earth Satellite Corporation, had scientific responsibility for major ERTS investigation of commercial fisheries application, and designed and coordinated Venezuelan Skylab experiment in coastal oceanography. With FWS responsible for integration of remote sensing technology into various aspects of FWS operational research activities.

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Twenty years experience with U.S. Air Force in aerial photography, photo processing, image interpretation, and cartography. Includes R & D efforts in developing/evaluating imaging systems. Currently providing technical and staff support to Texas state agencies in remote sensing/cartographic activities.

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Dr. McMurtry worked in the Information Processing subsection of the General Electric Electronics Laboratory from 1965-1967 where he was engaged in research and applications of pattern recognition. In 1967 he accepted a joint appointment with the Department of Electrical Engineering and the Ordnance Research Laboratory at The Pennsylvania State University. At ORL, he worked on various pattern recognition and control system problems. Since 1970, Dr. McMurtry has served as Co-Director of the Office for Remote Sensing of Earth Resources (ORSER) at Penn State. He has been the principal investigator on several projects involving the analysis, interpretation, and application of Landsat, Skylab and aircraft remote sensing data.

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Ph.D. University of Massachusetts

Dr. Mrazik received his Ph.D. in 1976, with a background in Forest Hydrology. His primary research interests concerned the effects of land use change on streamflow regimen. He is presently involved in the National Flood Insurance Program as a staff hydrologist with the Federal Insurance Administration in Washington, D.C.

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Remote Sensing coordinator for Civil Works Planning concerned with identifying and testing new remote sensing applications. Operates, maintains and improves System of Information Retrieval and Analysis for Planners (SIRAP). Involved with combining remotely sensed data with other planning data to formulate useful data bases for planners.

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Participates in preparation and coordination of EIS's; reviews and coordinates Survey, GDM, Master Plan and continuing Authority Reports, etc. Provides input and training for developing and implementing Corps water and related land resources planning guidance. Provides information and guidance in Fish and Wildlife Conservation and Management. Prepares response to Congressional, Agency and public inquiries. Performs special studies in support of Civil Works programs.

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Thirteen years experience Forest and Wildlife Management on Army installations and major headquarters. His present position is in the Recreation-Resource Management Branch, Office of the Chief of Engineers, Washington, D.C.

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1972-1975: While at Harvard worked as a research assistant on the National Science Foundation project entitled The Interaction Between Urbanization and Land: Quality and Quantity in environmental planning and design.

1973-1975: With the Georgia Department of National Resources, has responsibilities for the Resource Assessment Program which deals with the implementation of the GA/NASA RTOP and other programs dealing with water resources planning, coastal zone management, etc.

1971-1973: Consultant to the town of Barnstable, Mass. for their resource analysis and open space plan.

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Mr. Robinove has been with the U.S. Geological Survey since 1954, specializing in ground-water geology and later, in applications of remote sensing. He has been working in remote sensing applications research since 1961 and is presently studying the Landsat images for land capability mapping and and applications to disaster warning and assessment.

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Directs joint Census-NASA urban delineation and monitoring project. Directed Census Urban Atlas project which produced digitized files and automated thematic maps for the nation's largest metropolitan areas. Directs geographic research and development efforts for 1980 census. Responsible for the delineation of over 50,000 census defined statistical areas throughout the nation.

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Mr. Spann is currently vice-president of METRICS, Inc. where he has consulted with state, regional and local agencies concerning the operational use of remote sensing data. He has also been involved in remote sensing technology transfer efforts. Additional work has included a feasibility study of a state-wide natural resources information system, a cost benefit study of Information Analysis Centers, and a survey of the remote sensing activites of approximately 300 organizations in the U.S. Mr. Spann was previously a research scientist at Georgia Institute of Technology where he directed several projects involving computer processing of Landsat Data.

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Montana Fish & Game Department - 12 years

- Research on Fur Bearers, Big Game & Small Game Animal
- Management of Big Game & Small Game
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- State Wildlife Specialist
- Staff Leader, Denver Service Center

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- Staff Research Specialist - Endangered Species, Public Land, Marine Mammals
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Roy A. Welch received his Ph.D. degree from the University of Glasgow in 1968. He was a photo-analyst with the U.S. Government from 1962 to 1964, and served as Manager, Earth Sciences Department, Itek Corporation from 1968 to 1969. In 1969, he accepted an NRC-NAS Postdoctoral Research Associateship, in conjunction with the U.S. Geological Survey, to evaluate factors influencing the image quality of hyperaltitude photography. Since 1971, Dr. Welch has been on the faculty, University of Georgia, where he is an Associate Professor responsible for courses in photogrammetry, photo-interpretation and remote sensing. He is a member of the ASP, AAG, SPIE, British Photogrammetric Society, British Cartographic Society and Sigma Xi. He has served on various panels of the ASP, ISP, and AAG, and is the author of several technical papers on photogrammetry and image quality.

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After graduation, worked as a Naval Architect/Marine Engineer for two years and then two years in the U.S. Army as a Sanitary Engineer. Has held a Reserve Mobilization assignment with the U.S. Army Engineer School, Fort Belvoir, until recent retirement as a Major. From 1956 through 1971 worked for Arizona Department of Transportation, with 13 years in Photogrammetry and Mapping (Asst. Div. Engr.). Has administered the Arizona Resources Information System (statewide program) since its inception in 1972. Presented numerous papers in field of photogrammetry and on the ARIS program at technical meetings.

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Supervises research and development in geographic and cartographic techniques (including remote sensing), and their application to urban and regional analysis. Experienced in applying these techniques in advertising and marketing, civil defense, census planning, composite mapping of underground utilities, military intelligence, comparative urban studies, and in the teaching of these techniques and applications.

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Directs all market research and planning for Upland Industries Corp., a real estate firm operating in 13 western states. Activities investigated include residential, commercial, industrial, and recreational. Types of analyses conducted range from feasibility studies to environmental and economic impact assessments, and from public relation efforts to development projects in energy impacted areas. Manages a staff of nine professional researchers from various disciplines -- economics, finance forestry and range, geography, and journalism.

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B.S.	Central Missouri State College
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Accepted the position of State Cartographer of Wisconsin in August 1974, after 25 years of cartographic production experience with the Defense Mapping Agency, Aerospace Center, St. Louis, Missouri.

PART 5

AGRICULTURE

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CHAPTER I

INTRODUCTION

A. INTRODUCTION

The Agriculture Applications Survey Group was charged with the responsibility of assessing the usefulness of remote sensing (specifically Landsat follow-on capabilities) as a tool for agriculture. To the degree that this assessment is positive, users at all levels of the world food and fiber production system can benefit. These users of agricultural remote sensing data form a somewhat unique group. Potential agricultural users cover a wide spectrum from: hundreds of thousands of farmers; to large agribusiness organizations; to local, state, federal, and international decision makers. Levels of operational applications will vary according to the specific needs of these diverse individual users. To make Landsat follow-on data compatible with the diverse needs of this unique user community is a difficult task.

The world's supply of land is finite. The awareness of the significance of this fact will become more crucial as population increases and the demand for higher and higher levels of food production approaches the inevitable point where land resources become inadequate. In the coming decades, local, regional, state, national, and international agencies, charged with the responsibility for developing, inventorying, monitoring, managing, and forecasting worldwide agricultural productivity must improve their methods of data acquisition and dissemination.

A recent seminar on Retention of Prime Lands sponsored by the U. S. Department of Agriculture addressed a variety of national and world land resource problems. In the forward of the seminar papers prepared by Assistant Secretary of Agriculture, Robert W. Long, he states:

> "A frustrating lack of data prevents a clear picture of either the current situation or the probable future amount of land available or needed for agricultural production. In a situation this large and complex, it is important to gain a broad base of citizen and scientific input as a basis for public policy."

In the summary of findings of the conference report, the first statement relates to demand and states:

> Evaluating the future demand for food, fiber, and timber is a task involving a great many variables. The future responsibility of the United States in food, fiber, and timber production extends

far beyond the domestic requirements for these products. This necessitates the evaluation of world-wide demand, introducing variables such as population increases, patterns of consumption, trade opportunities, food aid needs, production capabilities of developing nations, global weather patterns, and fluctuation and general economic conditions.

Clearly, the demand for information is well identified. Much of the needed information could be acquired by remote sensing. An unsettling conclusion which arose from the conference revealed that technological improvements alone can no longer be relied upon solely to overcome production losses from a diminishing supply of arable land. Recommendations from that conference clearly identify:

The need for improved information concerning the earth's potential for producing food, feed, and fiber.

The need to monitor potential agricultural production from planting to harvesting.

It is the consensus of the Agricultural Applications Survey Group that remote sensing can:

Be used as a tool to improve the quality of our global information in these areas;

Make a significant contribution to our agricultural management decision process.

The Agriculture Applications Survey Group is charged with the responsibility of assessing remote sensing (specifically Landsat follow-on capabilities) as a tool for agriculture. A relatively small panel, the Agriculture Applications Survey Group contained: four members from the agriculture/industry community; three representatives from universities; two from the Department of

Agriculture; two from the National Oceanographic and Atmospheric Administration; one from a county water agency; and one member from the Canadian Department of Agriculture. To the degree our assessment is positive, users at all levels of the world food production system will benefit. Potential users of agricultural remote sensing data cover a wide spectrum from: hundreds of thousands of farmers; to large agribusiness organizations; to local, state, federal, and international decision makers. Levels of operational applications vary according to the specific needs of this diverse user group. To make Landsat follow-on data compatible with the needs of this unique user community is a difficult task.

To date, operational applications of remote sensing techniques in agriculture have typically depended on aircraft data collection systems. Landsat data have received limited operational use in agricultural programs, particularly in areas requiring sophisticated multi-stage satellite, aircraft, and the use of statistical models. Landsat potential can be significant, however, particularly when dynamic resources are evaluated. Reasons often stated for this lack of operational application include:

* Excessive time-delays in the receipt of data products after overpass;
* Low spatial resolution of products;
* Inappropriate spectral resolution of data product;
* An overall lack of information on the part of potential users.

It is the hope of the Agriculture Applications Survey Group that the above data characteristics will be altered as proposed for the Landsat follow-on mission.

The complete text of this paper indicates current and potential increases in applications of Landsat and the Landsat follow-on system by agricultural users in the areas of:

* Crop stress;

* Climatic information;
* Crops -- groundwater and stress;
* Agricultural land and water resources;
* Global and unique applications;
* Worldwide crop production estimation;
* Adjunct considerations;
* Selected applications;

which could occur provided improvements are made as proposed for Landsat follow-on in the following areas:

* Choices and sensitivity of spectral bands;
* Increase quantization (number of shades of gray or brightness levels);
* Ground resoluble distance;
* More appropriate equatorial crossing time (higher sun);
* Geographical registration of products;
* Improved data dissemination time.

B. APPLICATIONS

In considering the world-wide applications of remote sensing data in agriculture the quality of information resulting from analysis of satellite-sensed data is directly proportional to the quality and amount of available collateral data, the ground truth process employed, and the technical and practical training of the analyst. In the study of the range of potential applications of remotely sensed data no attempt was made to create an exhaustive list of present, potential or "hoped for" applications. As a consequence, some relatively popular, but less productive applications were intentionally ignored.

The Survey Group evaluated the significance of each particular capability of the present Landsat and proposed Landsat follow-on systems as presented to us and to the agricultural sector of our economy.

Each capability was rated in a relative sense. The scale used was:

+3	+2	+1	0	-1	-2	-3
Highly Desired	Desired	Improvement		Slightly Detrimental	Undesirable	Highly Undesirable

LANDSAT 1 and 2				
80 m Spatial Resolution	In operation, given and therefore, not evaluated.			
Signal/Noise - Moderate				
Spectral Range 0.5 - 1.1 µm				
Repeat Coverage	-2			
182 x 182 km mi. Format	1			
Mid-morning 9:30 a.m.	-1			
Digital Tapes - Raw data	-1			
* Data Delivery as presently experienced	-3			
* Image Quality as presently available	-2			
Incidental Stereo	1			
Geometry - Excellent				
LANDSAT C				
Add: 10.4 to 12.5 µm	2			
* Digital Tapes, Corrected	2			
* Data Delivery, Rapid (48 hr.)				
RBV Panchromatic	not enough known about specifications			
LANDSAT FOLLOW-ON				
30 m Resolution (except thermal)	3			
Add: Blue Band (water penetration)	2			
Add: Near IR (1.6 µm - mineral)	3			
Program Continuity	3			
Near-Noon - 11:00 a.m.	3			
Signal/Noise - Improved	3			
Geometry - Degraded at lower altitude	-1			

The Applications Study Group listed well over 100 applications

that could be accomplished with the aid of remote sensing capabilities proposed and/or planned for the follow-on project. After careful analysis of redundancies, this list was reduced considerably.

Basically, applications were viewed in relation to practices to which they could be applied within the normal management practices of the agricultural sector of our economy. The points of information application were considered (federal agency, state, local, industrial, farmer). As a result, a relatively small number of headings were developed for which remote sensing could supply a variety of information on such parameters as:

* Topographic relationships;
* Major soil characteristics (not detailed to specifics)
* Vegetative type, quantity and stress conditions
* Agricultural water, quantity and quality
* Management characteristics
* Miscellaneous applications

Agricultural applications reported herein were considered more in the form of groups of activities or uses under the following headings:

* Crop Stress
* Climatic Information
* Crops--Groundwater stress
* Agricultural Land and Water Resources
* Global and Unique Applications
* Worldwide Crop Production Estimations
* Adjunct Considerations
* Selected Applications

As a result of this grouping, for example, crop stress was considered as one application, even though it may involve a great number of crops, for reasons related to disease, insects, moisture,

frost, or heat. Macro or world-wide applications were considered as a separate group. The LACIE program was considered to be in this category.

CHAPTER II

APPLICATIONS

A. INTRODUCTION

In the process of reviewing possible worthwhile applications of remote sensing in agricultural production, a number of basic guidelines were recognized and used in the review process. The realities of the circumstances under which remote sensing will be used in agriculture were considered, and provided the basis for consideration of each major application. It was recognized that:

- Positive identification of a variety of agricultural information is not usually possible from remote sensing data (insect species, crop species or variety, disease pathogen, etc.) and collateral data are essential.
- There will be supplemental information available to persons making management decisions.
- Field verification (ground truth) data (site visits) were recognized as an integral part of the practices of most applications of remote sensing in agriculture.
- A very short delivery time is critical for most effective use of remote sensing in the agricultural management decision process; a 48-hour delivery time frame is required to be effective.
- Accurate calibration, registration, and geographic referencing will establish rigid requirements to be met by the system.
- Historical and supplemental documentation should be maintained to support the use of and increase the value of the data over time. Decisions based on an extended time frame will require this type of documentation.
- Satellite acquired data must be converted to information for use in the management decision process; without conversion and use, there can be no claim of benefit attributed to remote sensing.

- Finally, when considering world-wide applications, the quality of information resulting from the analysis of satellite-sensed data is directly proportionate to the quality and amount of available collateral data, the ground truth process employed, and the technical and practical training of the analyst.

1. Consideration of Applications

No attempt has been made here to create an exhaustive list of present, potential, or "hoped for" applications. The goal of the Applications Survey Group for Agriculture was to review the capabilities of the sensing package to be orbited on Landsat follow-on, relate that to recognized needs in the agricultural sector, and consider the level of feasibility of that application in relation to its importance to agriculture. As a consequence of this approach, some relatively popular, but less productive applications were intentionally ignored (tax map or ownership mapping, fallow land area mapping, etc.).

2. Selected Applications

The applications study group listed well over 100 applications that could be accomplished with the remote sensing capabilities proposed (and planned) for the Landsat follow-on satellite project. After further recognition of the similarities between many of the applications, and especially their dependence on the capability or characteristics of a specific sensor, this list was reduced considerably. The applications were considered more in the form of groups of activities or uses. As a result, for example, crop stress was considered as one application, even though it may involve a great number of crops, for reasons related to disease, insects, moisture, frost, or heat.

The objective was not to present an exhaustive list of possible applications (and no doubt more applications could be added), but rather to develop a group of applications of sufficient significance to justify efforts at further consideration of their usefulness. Applications presented here were considered feasible and productive when reviewed in the light of technical competency reported for the Landsat follow-on satellite system. Varying degrees of productivity are expected, but all are considered worthwhile.

Basically, various applications were viewed in relation to the practices to which they could be applied within the normal management practices of the

agricultural sector of the economy. The point of application of the information was also considered (federal agency, state, local, industrial, farmer). As a result, a relatively small number of headings for which remote sensing could supply a variety of information were selected. These include:

Crop stress;

Climatic Information;

Crops -- groundwater and stress;

Global and unique applications;

Worldwide crop production estimates;

Land resource inventory;

Adjunct considerations;

Information management of satellite-sensed data;

Selected applications.

It was considered important to discuss macro, or worldwide, applications as specific separate topics. The problems associated with such applications, as well as the significance they present in world economic development, international diplomacy and world food/energy/population relationships are substantial, and were set apart as worthy of much more serious consideration than time would allow by this group. The LACIE program was considered to be in this category.

B. AGRICULTURAL LAND RESOURCE INVENTORY

The value of the follow-on system for Land Resource Inventory is dependent upon at least two elements:

1) the ability of the imagery to distinguish agricultural characteristics, with or without ground truth, at a known degree of accuracy; and

2) the cost to the user of getting the information in the form it is to be used.

The cost of the information in the proper form must finally be measured against alternative methods of securing the same information where alternative methods exist, within the time constraints before it can be valued.

Based on recent literature, the ability to use this technology for land resource inventory has already been proven practical. The potential application is so broad that only statements can be made about specific future uses. The limits to its use can only be defined by the limits of

the imagination of potential users and the comparative costs of other methods when a specific use is examined.

In this report specific needs that are part of the land resource inventory are listed. This assignment has identified land resource potential which depends on other factors such as water availability. Many water-related needs are also specified in order to determine the potential.

It must also be recognized that needs will not result in uses of this new technology until proper communication of that technology is provided to the user.

Partial List of Needs for Land Resource Inventory

It is recognized that the following list of needs include some uses already in practice. It is necessary to be able to identify:

- Varying degrees of wet and poorly drained areas
- Annual or periodic flood plains
- Type of cover (e.g. forest, brush, treed savannah, savannah, short grass steppe, bareground, phreatophytes)
- Intensity of cultivation, including recently burned areas
- Current geomorphic process and stage
- Meso-relief
- Economic engineering - geologic materials (i.e., sands, gravels, quarry rock, etc.)
- Present crops and acreages
- Condition of crops (i.e., stress and source of stress)
- Stage of maturity of crops
- Soil color
- Agricultural materials such as potash, limestone, and gypsum.

Because land use potential is directly related to water, the following needs in that area are listed:

a. Groundwater

- Detecting regional structural features affecting the occurrence and movement of groundwater.

- Mapping geologic structural features affecting well yields, such as faults and joint patterns in consolidated rocks.
- Locating regional recharge and discharge areas for aquifers, such as lakes or springs.
- Location of areas of shallow groundwater, as related to subsurface drainage.
- Determination of infiltration potential of near-surface soil horizons.
- Determination of depth to water when greater than 5 or 10 feet.
- Determination of aquifer thickness.
- Determination of location and thickness of perching layers and confining beds.
- Determination of aquifer transmissivity, porosity, storage coefficient, and other parameters.
- Determination of regional chemical composition of groundwater, particularly salinity.
- Determination of polluted zones in the aquifer.
- Alluvial valley trains
- Geologic structure for dam site selection

b. Surface Water

- Determination of regional water quality variations in streams.
- Water quality stratification in reservoirs.
- Regional percolation from stream channels, unlined canals, and irrigation.
- Determination of drainage basin watershed characteristics which determine runoff and sediment load.

- Provision of topographic information in unsurveyed areas and updating of information in surveyed areas.
- Site selection for stream gaging sites, turbidity measurements, and water sample collection.
- Site selection for dams and canals, related to soils and geology.
- Characteristics of snowpack for predictions of runoff.
- Flooding analysis, related to roads, irrigation structures, industrial sites, and farms.
- Detection of thermal pollution of rivers and lakes.
- Determination of sources of water pollution.
- Water seepage from coastal areas to intercept for pumping before it is polluted by salt water.

It is recognized that the preceding list of needs for potential land use planning may not be complete. Such a task is comparable to a person being asked in 1950 to predict all the uses that might be made of a computer. Many of the uses made of the computer today would not have been named.

It is also recognized that some of the needs listed above will likely be beyond the technological possibility of the imagery, particularly those demanding subsurface vision. Correlations of these things with visible characteristics may result in such use in the near future. Only human imagination and the economics of a given application will limit its use in securing information for land use analysis.

In general, this technology will be used on anything that is distinguishable on the imagery, and when the cost is less for the quality of the needed form of the product than any alternative. This will be true both when ground truth will be used with a multi-sampling system and when ground truth is unneeded because recognition accuracy is known and is sufficient for that need.

A major key to the amount of use made of this technology and the speed at which it is accepted will be the software and the computer costs associated with the above land use data. Ideally, the capability should be present for each need listed above to be mapped out by the computer printer from the tape received from EROS.

C. CROP STRESS

Remote sensing data, whether it is photographic film or other forms, can serve the user in two unique ways.

1. Provide an excellent permanent record of crop conditions;
2. "See", or record, characteristics of the crops in additional wavelengths besides those visible to the human eye.

The value of the Landsat follow-on system capabilities for detecting crop stress can be objectively compared to marine charts.

If a ship is navigated from one port to another, and in so doing traverses a river and the open ocean, the prudent captain will have small-scale charts for the ocean crossing and large-scale charts for at least the main harbors and rivers. It would not be feasible to use large-scale charts for the complete voyage even if such charts were available, due to the vast number of charts required, etc. Similarly, it would be impractical as well as dangerous to rely on small-scale charts, such as 1:1 million sailing charts, for the complete route.

The prudent captain would also utilize harbor pilots and arm himself with tide tables, light lists, etc., before embarking on the above type of voyage.

Proper utilization of the Landsat follow-on system will necessitate similar supplementary information. It is no more feasible to restrict the study of crop stress and/or inventory to only Landsat 1:1 million scale imagery or tapes than it is to try to navigate a ship with only a 1:1 million scale chart.

1. Expected Capability of Landsat follow-on

The Landsat follow-on Thematic Mapper resolution will detect limited areas of crop stress. The crop stress analyst needs supplemental ground truth for selected areas in the form of soil and salinity maps, weather data, large scale color and color infrared imagery, crop calendars, planting configurations (flat vs. bed, etc.), typical crop rotations and acreages for the areas. He also needs

information on land leveling history, expected irrigation patterns (furrow vs. flood vs. sprinkler), weed and insect species expected in the area, method of fertilizer application (dry or liquid, injected or drilled, ground or aerial application) and type (mainly nitrogen, all three major, mainly trace, etc.), harvest aid chemicals employed (desiccants, defoliants, ethylene inducer ripening agents, anti-sunburn agents, hormones, etc.; type, method of applying and timing of insecticides and herbicides, crop varieties (e.g. normal, dark or light green leaves, stormproof or open boll, sweet or field corn, short or long stapel, etc.). Only when supplemental information is available for at least limited areas can crop stress be properly interpreted from Landsat images. The identification of areas of stress in crops is the major source of useful information from satellite imagery of importance to decision-makers during the crop growing season.

2. Landsat follow-on Capabilities for Specific Crop Stresses

(1) Moisture Stress If sufficient data are available for weather, irrigation district boundaries, planting dates, soils, salinity, diseases and insects, the Landsat follow-on should provide a crude but useful measurement of moisture stress. Recognition of moisture stress in relatively small areas will probably not be possible due to inadequate resolution.

(2) Salinity Availability of salinity maps and knowledge of irrigation methods for the area should permit limited detection of crop stress due to salinity. Landsat follow-on resolution will not be sufficient to detect typical salinity effect of clumped vegetation, white salt patterns and altered reflectance in small areas.

(3) Nutrient Deficiency Gausman, Gerbermann and Wiegand (1975) claimed that 1.1 hectare or larger areas of chlorotic sorghum could be detected via Landsat 1 band 5. Practical application would, however, necessitate larger fields, relatively homogeneous leaf canopies and supplemental knowledge of soil types, nematode populations, etc.

Determination of additional nutrient deficiencies via Landsat follow-on would also require similar information as well as knowledge of fertilizers applied, soil pH, etc.

(4) Disease Landsat follow-on may have sufficient resolution to detect the relatively large areas of disease, e.g. root rot, with the typical circular pattern, and should be able to detect many stress patterns which, with supplemental information, can later be identified as areas of plant disease. It is not expected to have sufficient resolution to detect diseases that sometimes appear only as widely separated small areas, such as verticillim wilt.

(5) Insect Damage Landsat follow-on is expected to be of very limited value for detecting most insect damage, due to the relatively small area of a field or plant involved. Insects that devour large areas of leaf canopy, or otherwise change canopy reflectance, or cause growth of detectable fungi (e.g. sooty mold), should be detected by Landsat follow-on if sufficient area is involved.

(6) Other cases of stress may occur infrequently, such as that caused by fire, floods, or frost. They should be detectable from Landsat follow-on imagery.

D. FUTURE NEEDS

If Landsat follow-on is to be a practical tool for detecting crop stress, it must:

1) Provide imagery to users within two weeks or much less of date of imaging.

2) Have at least as good resolution as Skylab S-190B camera.

3) Be used in conjunction with as much supplemental information as needed to properly interpret crop stress.

4) Provide data (imagery, etc.) at a reasonable price.

5) Be employed by interpreters familiar with the management intricacies of modern agriculture.

E. CLIMATIC MODELING AND INFORMATION

1. NOAA Landsat Data Requirements for Crop/Climate Modeling and Assessments

NOAA, through its Center for Climatic and Environmental Assessment (CCEA) is presently participating in the tri-agency (NOAA-NASA-USDA) Large

Area Crop Inventory Experiment (LACIE). This test program uses remote sensing technology as a means for developing improved global wheat production forecasts with emphasis on accuracy and timeliness.

NOAA's responsibility to the LACIE program includes the development, test, and application of computerized models which relate the impact of weather to crop yields. These models are constructed by comparing many years of historical data on weather and yield, and establishing a statistical linkage between them. Different models are used for different wheat areas, and the models allow for a trend to higher yields, due to changes in farming methods such as new grain varieties or greater use of fertilizers. Weather data for the current year (beginning when the previous crop is harvested) are collected by crop district, county, or equivalent crop area and are used with the regression model to project the yields for the coming harvest.

The weather data include monthly averages of temperature, precipitation, and in some instances, potential evapotranspiration, which serves as a measure of stress to which the crop is being subjected.

In addition to the model development, CCEA's Assessment Division in Washington, D.C. prepares a weekly climatic assessment for the areas under study to assist the LACIE Analyst Interpreters in diagnosing Landsat imagery. The weather parameters which are covered include weekly surface temperatures, cloud cover, cloud type, precipitation (type and intensity), and major weather systems affecting the regions under analysis. Although a considerable amount of weather data and analyses are derived from the World Meteorological Organization Global Telecommunications System (WMO/GTS), much use is made of satellite photos in assessing the climate pattern. Currently the state-of-the-art is most effective when used in conjunction with some form of ground truth information. For example, one visual and two IR composite hemispheric photos from the NOAA-4 polar orbiting satellite are analyzed daily. Estimated precipitation is correlated with ground truth data at specific points to provide a measure of the total precipitation for an area. In the absense of ground truth, the photos are analyzed subjectively and potential areas of precipitation are identified. This procedure is necessary in the Southern Hemisphere where data are scarce. The same holds true for India, especially during the monsoon season, because few weather reports with precipitation amounts are received from that country.

Satellite photos are also valuable for determining cloud cover and the extent of snow cover from regions which do not furnish weather reports over the WMO/CTS.

At present, CCEA is not using Landsat data for direct input to the crop yield/weather models. This does not preclude the possible use of this data at some time in the future. Considering the capabilities of Landsat, the remote sensing weather parameters measured are somewhat restrictive. For example, an important input to the crop/climate equation is the amount of total precipitation which occurs daily. At this time the information can be estimated from photo imagery only in a qualitative sense. The same is also true for soil moisture. With regard to snow, Landsat can provide a two-dimensional picture, but what is needed is a three-dimensional snow-depth capability which would provide a quantitative measurement of potential water and runoff in the snow pack. Another critical element is temperature. Indications are that Landsat will be able to measure this parameter to within a plus or minus 6-degree accuracy absolute and a plus or minus 2-degree precision relative. However, for input to the crop yield calendar models, a precision of plus or minus 1-degree is required. Preliminary analysis indicates that minimum temperature is the primary factor related to spring wheat planting variation and wheat development through heading. After heading, maximum temperature is a principal element in advancing the development stage toward maturity. Temperature sensitivity by this model shows that a 1-degree Fahrenheit temperature bias during the spring season produces approximately a 2-day difference in maturity date.

To be an effective tool for assessment work, remote-sensed data must meet the following criteria.

It must be available on a timely basis and in a form which will facilitate integration with available ground truth information. To be timely means that the output must be relatively current. A 10-day to 2-week delay greatly diminishes the value of these data for assessment work. A 1 to 2-day delay would probably be acceptable.

Soil moisture determination in theory would be a useful parameter in crop/climate modeling efforts. The fact remains that accuracy of soil moisture measurements taken by skilled technicians on the ground is at best questionable. How to get an adequate soil moisture profile from Landsat needs to be carefully studied. If achieved, another consideration

is related to extension of a sample to the larger area covered by the crop of interest. This is a problem that will have to be resolved before operational use of these data can be achieved in assessment work over large regions.

Other proposed Landsat data, temperature and radiation, will require a developmental period to evaluate their possible usefulness over currently available data. It is not possible to make this determination without first attempting to use and evaluate these new data. The magnitude of possible improvement over existing demonstrated techniques is small and the cost of achieving this improvement may prove to be larger than warranted. This cost is in part related to special equipment needs and operational support necessary to operate the equipment once installed.

To properly assess the impact of weather on crop growth in overseas areas, the CCEA Assessment Division would welcome some feedback from Landsat imagery which would indicate the stage of the crop growth, such as emergence, heading, and even the starting dates of planting. Indications are that Landsat follow-on will have the necessary resolution to provide this data, but only in a nonquantitative sense.

In summary, Landsat data are useful and effective as ancillary input to ground truth in assessment of climatological parameters. It is available once every 18 days for coverage of the same area and will be reduced to 9 days with the Landsat follow-on satellite. This is in comparison to daily reports from NOAA satellites. The qualitative nature of the data, however, precludes its consideration in development of statistical crop/climate models. Until such time as Landsat can provide quantitative climatological input, to the precision needed, in a timely and cost effective manner, its expected use to CCEA will be limited to a contributory, subservient role.

2. Agriculture Moisture Demands (Surface Temperature)

The National Environmental Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA) at present provides image processing of digital data received from meteorological satellites, both polar orbiting and geosynchronous (NOAA-4 and GOES). The image data are cloud displays of visual data and thermal IR. Limited quantitative processing of the

digital processing is being done at the present time. This quantitative processing is in the form of vertical temperature profile sounding information and sea surface temperature determination. The data retrieved from the quantitative processing of meteorological satellite data are sent to the National Meteorological Center's global data base for use in numeric forecast models. No quantitative processing of satellite data to determine surface temperature over land areas is presently done within NESS, although techniques have been developed to determine clear radiance surface temperature over land and sea areas down to grid meshes of about 25 km from GOES VISSR (Visible and Infrared Spin Scan Radiometer) data. These techniques of retrieval have been blended with surface measures of sea temperature and air temperature to give a better spatial density of both measures. No requirement presently exists for NOAA/NESS to provide operational products of surface temperature.

Determination of surface temperature for use in plant moisture demand assessment requires the information to be of high spatial density and received in a timely manner. Operational meteorological satellite digital data provides for the rapid throughput of the information, but lacks the necessary spatial density. Landsat follow-on Thematic Mapper will provide the necessary spatial density but will lack continuous coverage of a given agricultural area and fast throughput (every 9 days). Information from the Thematic Mapper will also have to address the problem of cloud contamination. This is an ever present problem with surface temperature determination, and will be a critical problem with limited area coverage and a nine day return period.

3. Applications

Technical working groups within NASA working with specifications of the Thematic Mapper have identified several application areas. These areas include detecting plant water stress due to (1) need for irrigation, (2) soil salinity, (3) shallow and droughty soil, and (4) Nematodes, indicating occurrence of rainfall, measuring soil temperature for indicating when soil is warm enough to plant crops, studying occurrence and pattern of freezes, monitoring thermal pollution, detecting springs and subsurface flow into lakes, rivers and oceans, estimating evapotranspiration of farmland, forest, and rangelands, and estimating water evaporating from lakes, ponds, and reservoirs.

Probably the most critical point that can be raised with regard to the use of the Thematic Mapper in surface temperature determination is the throughput time of the data to the user in a form sufficient for the information to be worthwhile in moisture assessment. As the case with operational meteorological satellite information (even though the spatial density may not be sufficient) throughput time (for image information) is 30 minutes. It has been demonstrated that digitized data can be quantitatively analyzed for surface temperature with a grid mesh of 25 km and a throughput time of less than 30 minutes. It is this type of throughput time that must be addressed when considering the applications of the thermal data listed above.

Quantitative data reduction from the Thematic Mapper for determination of surface temperature will be sizeable. Currently no research is underway or has been planned to analyze these data quantitatively and relate the measures to those currently used in moisture demand and assessment. Considerable computer resources are necessary to achieve this. Some research must address quantitative processing of the Thematic Mapper information. The spatial resolution is sufficient for detailed moisture information on the cloud free areas, but to provide continuous moisture information, some backup means should be considered in the event of persistent cloudiness.

F. CROPS - GROUNDWATER AND STRESS

1. Remote Sensing Research - High Water Table Conditions

Thermal infra-red aircraft missions for detecting shallow groundwater have been successful in South Dakota (Myers and Moore, 1972). These studies showed that a surface emittance anomaly could be used to locate near-surface groundwater in glacial drift. However, the principles involved in heat storage and transfer also apply to shallow, unconfined water tables under conditions experienced in many agricultural areas. The authors concluded that pre-dawn August thermography conducted under certain prescribed meteorological conditions was optimum for interpretation of near-surface groundwater occurrence.

In a study of high water tables on the Kansas Bostwick Irrigation project, the Remote Sensing Institute of South Dakota State University,

cooperating with the U.S. Bureau of Reclamation (Ryland et al, 1975), used remote sensing technology to determine depth to water tables. The study, using corn as an indicator crop, showed that both Landsat 1 and aircraft remote sensing data correlated significantly with water table depth measured in observation wells throughout the District. Landsat 1 MSS band 6 for May and MSS band 7 for August correlated significantly (0.01 level) with water table depth for 144 observation wells.

Abdel, et al (1971) evaluated diurnal thermal measurements of soil surfaces for soils having water table depths from 0 to 1.2 m. They found that water table depths of 0.0 m and 1.2 m produced a maximum blackbody temperature difference of 20° C. They found that the maximum apparent temperature differences associated with water table depth differences occurred between 2:00 pm and 4:00 pm with an inversion of the relationship after midnight.

The capability for measuring evapotranspiration is important in an evaluation of water table depths. In a Skylab project, multispectral reflectance and emittance data were evaluated by Moore, et al, 1975, for prediction of evapotranspiration rates and soil moisture for an irrigated region of Southern Texas. S-192 data were used in successful prediction of the 0 to 30 cm soil moisture for fallow surfaces, and for surfaces of variable crop cover. Evapotranspiration maps were produced using a prediction model and Skylab emittance data. Enhancement methods for thematic mapping using digital scanner data were developed. The recommended spectral regions for scanners on future satellites should include at least the 10.2 - 12.5 μm, 1.55 - 1.75 μm, 0.56 - 0.61 μm, and 0.98 - 1.98 μm spectral regions.

Research studies in Kern County, California (Estes, et al, 1975) are being directed toward detection and delineation of water tables that are perched near the surface. Nearly 47,000 hectares in the county have perched water tables within 3 meters of the surface. Investigations include both high altitude color infra-red photography and Landsat multispectral imagery to determine their utility for this task. The use of thermal infra-red imagery is also being investigated for this problem.

Thermal infra-red imagery used on a Jefferson County, Kansas, test site revealed that anomalous areas of more intense thermal radiation coincided with relatively shallow depths to groundwater or bedrock. (Myers and Stallard, 1974).

2. Mission Parameters, Spectral and Spatial Resolutions

The only intensive research investigation of record that has explored the reflective portion of the electromagnetic spectrum for detecting high water tables is the one described earlier by Ryland, et al, 1975. In that study, Landsat band 6 in May and band 7 in August correlated well with water table depths using corn as an indicator crop. The specific effects of water table on physiological characteristics of crops have not been investigated. Therefore, it can only be surmised that the influences are related to effects of moisture availability, aeration, and perhaps the indirect effects of salinity. Temperature measurements of crops in relation to water table depths were significant, indicating the thermal band of 8.7 to 11.5 μm is suitable for this purpose.

Studies by Myers and Moore, 1972, and Abdel, et al, 1971, indicate that thermodynamic conditions creating surface temperature anomalies for bare soils are dissimilar under conditions of water tables very near the surface, on the one hand, and deeper than about 1.5 meters, on the other hand. This results in the apparent respective optimum times for thermal sensing of pre-dawn for deeper water tables and mid-afternoon for very shallow water tables.

Various crops used as indirect indicators of water table depths respond differently because of variable physiologic response of different crops to environmental conditions. Cotton, on the one hand, has been found to be extremely responsive to changes in environment as exhibited in spectral and thermal characteristics, and is an excellent indicator crop for high water table, salinity, and evapotranspiration measurements. Sorghum is intermediate in response, and corn is one of the poorer indicators of stress conditions. Estimates of depth to water table mode from data collected on the Thematic Mapping Mission should be made, based on measurements in fields of the same crop. This will also minimize differences in emissivity.

3. Remote Sensing Research

The Kern County Water Agency in California, located within a typical productive irrigated area, has indicated that the existence of saline-alkali soils in a study area affects crop yields (Estes, et al, 1975). The Geographical Remote Sensing Unit at the University of California in Santa Barbara (GRSU) first identified the dimension of

the saline alkali agricultural damage based on photointerpretation and extensive ground truth. Recently, a quantitative procedure for assessing salinity damage based on field tonal (density) values has been developed and is highly correlated with a field average of electrical conductivity values.

Studies by Wiegand, et al, 1975, used data from Skylab and aircraft for detecting and surveying saline soil areas in Texas. Differentiation between saline and non-saline rangelands may be possible using Skylab satellite black-and-white film because of more bare soil background showing through vegetation in saline areas. Differentiation among saline and non-saline cultivated soil sites was not possible using black-and-white or color film, but vegetation and bare soil MSS digital data difference or ratio may be a good indicator of salinity levels at aircraft and satellite altitudes. MSS infra-red wavelengths were superior to visible wavelengths for soil salinity detection. Thus, aircraft or spacecraft information may be useful for detection of saline soil in rangeland areas by measuring the bare soil showing through vegetal areas and cultivated areas by measuring contrast between the vegetation and adjacent bare soil. Cost/benefit studies indicate that satellite information may give an overall economic saving to saline soil management compared with aircraft or photointerpretive information.

The first year of a two-year research project on early detection of saline seeps by M. Horton and D. Moore from South Dakota, and associates from Montana and North Dakota, has produced favorable results. Multispectral photography and thermal imagery from aircraft missions are being related to known ground conditions. Crops growing in the test seeps are used as indicator plants for detecting saline sites of various degrees of seriousness. Lack of vegetation growth in places is indicative of serious salinity problems associated with saline seeps.

Ektachrome IR and black and white infra-red film with an 89-A filter were used by Myers, et al, 1963, in an application of photointerpretation in estimating the severity and extent of known salt affected areas in cotton fields. The film emphasizes the IR reflectance of healthy green vegetation which appears bright red or pink on the photographs. Cotton plants affected by salinity appear as darker shades of red. These studies utilized cotton as an indicator plant to relate the salinity in the 0- to 1.5-meter profile depth at some reference

locations to that at a number of prediction sites.

Multiband photography of salinity in cottonfields, taken with a 9- lens camera by NASA, isolated specific wavelengths where reflectance contrasts can be detected. The near-infra-red wavelengths of 0.67 - 0.9 μm, 0.75 - 0.9 μm, and 0.77 - 0.9 μm exhibited by far the best tonal contrasts for detecting the extent of salinity as registered by plants (Myers, et al, 1970).

The remote sensing of plant canopy temperatures for detection of salinity also is feasible (Myers, et al, 1966). If dissolved salts are present in the soil solution, the osmotic potential of the soil water is increased. Consequently, the soil water is rendered less available to plants. A reduction in the rate of water uptake by roots and a decrease in the water content of the stalks are among the first detectable plant responses to salinity. Thus the transpiration rate is reduced and the accompanying canopy temperature increases.

It is significant that spectrophotometer reflectance curves from cotton plants affected by various degrees of moisture stress are different at wavelengths less than 1.35 μm, but are nearly identical at longer wavelengths. It has been shown by Myers, et al, 1966, that leaves from different cotton plants affected by various amounts of salinity have reflectance curves with substantial differences, between 0.5 and 2.5 μm, throughout the entire spectrum. Such contrasting reflectance characteristics may provide the means for remote detection and identification of these phenomena.

4. Photographic Sources

In establishing a correlation between photographic color contrast and the average salinity in the soil profile, using color-infra-red film, a depth increment that is fairly representative of the rooting depth must be selected. Also, timing of the measurement must be correlated with the maximum contrasts of plant color and height. In the case of cotton in South Texas, the ideal timing is usually just before the cotton bolls begin to open. In a reasonably uniform deep soil, cotton plants at the boll stage are utilizing moisture and nutrients to a depth of about 1.5 m. Photographs of an area affected by salinity can be studied without special equipment, and a great deal can be deduced from the

observations. It is desirable, however, to take advantage of instrumentation and techniques that have been developed to automate the procedures and to take advantage of the precisions offered by instrumentation. Minimum desirable equipment for such studies includes a densitometer for measuring film density and a film-viewing table, and methods to analyze the digital scanner products.

5. Landsat follow-on Imagery Use

Agricultural water resource applications using remote sensing imagery have been initiated by numerous universities with the feasibility phase of these studies being substantially funded by NASA. Cooperation with potential user agencies has maximized the return of this effort by providing consultant review of the research programs and important ground truth data. It is anticipated that an extension of these initial investigations will be made to utilize Landsat follow-on data for world-wide identification, monitoring and prediction of agricultural water resources.

6. Water Storage

In areas of irrigated agriculture, monitoring of surface water storage facilities can lead to accurate estimates of the available water supply which is ready for immediate use. Recognition of individual wells or well fields may also be useful in determining the availability of groundwater as an alternate agricultural water supply, limited by installation capacity and hydrologic conditions.

Interior groundwater basins, in semi-arid areas, are quite often recharged by water management agencies if it has been determined that they are in a state of "overdraft". Recognition of replenishment facilities and transmission structures utilized in the recharge operation will provide circumstantial evidence that a limited groundwater supply exists in that area.

7. Distribution Systems

Imported water supplies can be traced when surface conveyance structures (canals, pipelines, etc.) are identified and monitored for their status (i.e. leaks), or surrogates for sub-surface pipes are recognized (i.e. linear, tonal variation in soils due to excavation).

Identification of these facilities is primarily dependent on the spatial resolution of imagery provided by NASA systems. Current Landsat data can be used to identify most large facilities and many elongate transmission units. Natural irrigation or drainage channels with a width of 8 to 10 ft. can be recognized and some pipelines are visible. Irrigation water applications systems which establish a definite vegetative growth pattern are also identifiable. Some water installations, such as individual well locations, can be recognized in conjunction with allied structures.

8. Water Application

An approximation of the total water demand for an agricultural region can be made if the major crop species are identified and an irrigation efficiency factor for that area can be developed. To a less accurate degree, even the binary classification of irrigated/non-irrigated lands can be employed for this purpose if some collateral information is available to develop the average regional water application rate. In determining what the total water requirements are for a specific area, the mechanics of water application must also be considered in order to establish a reasonable determination of the current irrigation efficiency employed. Is field flooding common or is the irrigation water applied through use of open ditches or pipes? Therefore, water supply inventories coupled with the water demand estimates and water application practices are important parameters necessary to the efficient prediction of agricultural yield. For instance, if the required water supply is not yet available for any particular year, reductions in total yield can be predicted.

Estimations of future rates of irrigated agricultural expansion must consider the availability of useable water. Water that is collected in basins sometimes contains salts that render it unacceptable for farm use. A salty crust or ground surface signature may provide the clue to brackish water or saline soil identification. Visual monitoring of the water supply distribution system construction may also provide evidence of planned agricultural expansion. The dimension and distribution of the structures can be used to estimate the anticipated water flow capability and management strategy of the new development. If a per-acre yield has previously been established for the original area,

then an estimate of potential future crop yield can be "predicted" for the new expansion.

9. Water Use Limitations

Inventorying conditions which might limit the use of land for agriculture can aid planners in determining the ultimate size of this industry within a limited area. Research is now being conducted by use of Landsat imagery to identify perched water accumulations, saline soils, moisture deficient soils, hard rock areas without adequate soils, and areas where topography is too steep for normal cultivation.

Visual examination of imagery acquired immediately following a rainstorm will reveal the presence of tight soils, where water is ponded, which will, in many cases, limit the variety of crops which can be grown or the yield which they will provide.

Monitoring of the flood stage spread of water from streams or from reservoir releases will be useful in determining "floodplain zones" and the limiting effects to agricultural development or maintenance thereof.

The thermal infra-red channel on board Landsat follow-on would provide unique information relative to the thermal anomalies associated with perched water tables and soil moisture.

10. Water Waste Disposal

In irrigated areas where drainage problems have developed, wastewater disposal ponds and conveyance systems may be used in the problem correction process. Recognition of these facilities can be an early warning signal that the agricultural development is undergoing a reorganization in order to survive.

11. State-of-the-Art

The following chart, Table II-1, has been prepared to illustrate the "State-of-the-Art" of Landsat remote sensing techniques applied to agricultural water resource applications. It is anticipated that in the very near future, with the cooperative aid of user agencies, research findings will become operational and made available to interested potential users through an improved network of information transmission and educational programs. To realize this goal, the Landsat follow-on

TABLE II-1
NASA - APPLICATIONS SURVEY GROUP
AGRICULTURE
LANDSAT IDENTIFICATION CLASSIFICATION

	STATE OF THE ART (With 80 meter resolution)			TEMPORAL REQUIREMENTS	
	Operational	Development	Research	Frequency Coverage	Data Delivery
WATER STORAGE					
Surface Reservoirs					
Artificial	X			@ 9 days	@ 1 week
Natural	X			@ 9 days	@ 1 week
Water Quality		X------	------X	@ 9 days	@ 1 week
Subsurface Reservoirs					
Recharge Facilities	X			@ 18 days	@ 2 weeks
Well Fields			X	@ 18 days	@ 2 weeks
Transmission Facilities			X	@ 18 days	@ 2 weeks
Wells			X	@ 18 days	@ 2 weeks
DISTRIBUTION SYSTEMS					
(Canals)					
Lined	X------	------X		@ 18 days	@ 2 weeks
Unlined	X------	------X		@ 18 days	@ 2 weeks
(Pipelines)					
Surface	X------	------X		@ 18 days	@ 2 weeks
Subsurface			X	@ 18 days	@ 2 weeks
Natural Channels	X------	------X		@ 18 days	@ 2 weeks
WATER APPLICATION					
Field Flooding		X------	------X	@ 9 days	@ 2 weeks
Ditch Deliveries			X	@ 9 days	@ 2 weeks
Closed Systems (Pipes)	X------	------X		@ 18 days	@ 1 month
Irr. Need Recognition			X	@ 9 days	@ 1 week
Irr./Non-Irr.	X			@ 18 days	@ 2 weeks
Crop Identification	X------	------X		@ 9 days	@ 1 week
Areal Limitations					
Perched Water			X	Daily	Daily
Saline Soils			X	@ 18 days	@ 2 weeks
Moisture Deficient Soils			X	Daily	Daily
Hard Rock	X------	------X		@ 18 days	@ 1 month
Steep Slopes	X------	------X		@ 18 days	@ 1 month
WASTEWATER DISPOSAL					
Evaporation Ponds	X------	------X		@ 18 days	@ 2 weeks
Surface Conveyance Systems	X------	------X		@ 18 days	@ 2 weeks

systems must be more receptive to user agency temporal requirements in terms of both repetitive coverage and delay time between data acquisition and delivery to user. Widespread use of satellite imagery to determine when crops should be irrigated will result when the data are received within a few days after the flight was made. This one innovation could result in appreciable conservation of our limited water supply and the energy necessary to move this natural resource. Table II-1 suggests temporal guidelines for the applications discussed.

12. Visual Monitoring

A knowledgeable observer with the improved resolution imagery of Landsat follow-on should be considered as an important factor in evaluating the world's irrigated agricultural resource and the related water supply. His use of the temperature sensitive band will provide an additional tool for use in the water-oriented activities of agriculture. This will greatly aid in the monitoring of water bodies and moisture laden soils.

It is quite possible that estimates of crop yield can be greatly improved, on a world-wide basis, if the importance of irrigated agriculture can be identified as a factor employed to overcome the production problems that result from changeable weather conditions.

Crop yield reduction estimates can be made by visual inspection of imagery from cropped lands. It is very probable that test plot areas could be identified, in foreign lands, for this purpose. The visual estimate of crop yield could be compared with that computed estimate of grain production so that the current system can be improved.

13. Basic Considerations (High Water Tables)

Over 160 million acres of farmland in the U.S, once with high water tables in the rooting zone of crops, have been drained. More than 20 million acres are still in need of drainage. Design of new drainage systems, maintenance of old systems, and management of cropping systems depends upon a knowledge of the depth to the continually fluctuating water table.

Any crop may be affected by high water tables but forage crops are frequently grown in areas thus affected because of easier management characteristics. It is estimated in the 1970 census that there are about 5 million acres of forage crops, a large portion of which is alfalfa in

the Southwestern states of the U.S. About half of this area, or 2.5 million acres, is affected by high water tables.

Excessive water in the soil profile occurs in several ways; as springs or seeps resulting from water surfacing due to buried barriers or undulating topography; as high water tables resulting from an accumulation of excessive water over a restricting layer in the profile, and others. The term high water table as used here refers to an accumulation of gravitational water that at some time during the year interferes with or influences agricultural plant growth.

14. Effects of High Water Tables

One of the most serious aspects of excess water management is that of controlling fluctuating water tables within or close to the root zone. Most experts estimate that roots of most agricultural plants are materially damaged if submerged in water for more than about five days during the hot part of the growing season.

In the case of irrigated crops, uncontrolled, fluctuating water tables usually result from over-irrigation or inefficient drainage systems. When water tables are allowed to rise and remain in the root zone for an extended period, the submerged roots are often killed. Sometimes the plants become shallow-rooted and must be irrigated accordingly -- usually more frequently, which in turn could aggravate the high water table problem. Furthermore, such plants no longer have root systems, capable of providing nutrients for maximum growth. In addition, the water of the shallow water table often is high in salinity supplying excess salts for accumulation in the soil profile with the upward water movement associated with capillary rise and evaporation.

Low lying agricultural lands which frequently are waterlogged are commonly used for forage crops, particularly pasture. High fluctuating water tables and water standing on the surface for long periods kill many of the more desirable species of grasses and legumes. They are replaced by weeds of low palatability. Some pasture plants, such as reed canary grass and strawberry clover, can endure wet conditions. But quality and quantity of pastures are generally greatly reduced on poorly drained land.

Goedwaagen pointed out that young grassland has a more flexible root system than old grassland, and while under certain conditions, young grassland may be able to adjust its root system to a falling water table, old grassland may not be able to do so under the same conditions. Old grassland has generally a more shallow root system than young grassland and is, therefore, more susceptible to injury by summer drought. Estimation of the underground water situation is therefore of high importance.

15. Management of High Water Tables

It is important to realize high water tables are not always undesirable. There is much evidence that it is possible to produce good crops under high water table conditions using controlled irrigation and drainage practices. Under most irrigated conditions, it is desirable to maintain water tables at depths of five or more feet below the soil surface, especially where salts are a hazard.

A three-year study of evapotranspiration of alfalfa grown in tanks with various depths to water table at Reno, Nevada (Myers and Tovey, 1958), showed that alfalfa is a heavy user of water from a shallow non-fluctuating water table of good quality. Alfalfa that was not irrigated produced nearly as much as irrigated alfalfa with a comparable water table. Water tables studied were at depths of .61, 1.22, and 2.44 m. Of course, ample water must be applied at shallow depth in establishing alfalfa stands. The use of water from a high water table by alfalfa is undoubtedly the main reason why alfalfa produces so well during drought years.

In the Lower Rio Grande Valley of Texas, serious water shortage conditions led to research which has shown that cotton uses a substantial amount of water from a high water table. With a water table at six feet and water that is fairly high in salinity, about forty percent of the cotton water requirement was supplied by the water table. A nine-foot water table supplied twenty percent of crop requirements.

Under the above conditions, a lowering of the water table may actually lead to a decrease in crop yield. Such might be the case where crops (particularly alfalfa which is a phreatophyte) depend on moisture from the water table to sustain plant growth.

A study group from the United States that visited Russia (USDA, SCS, 1958) reported that in at least one area emphasis was placed on the desirability of maintaining a high water table to reduce the amount of irrigation water needed for cotton production.

The management and utilization of high water tables, in many areas considered an evil, can under favorable circumstances be a wise use of a natural resource.

16. Salinity

Saline soil conditions reduce the value and productivity of considerable areas of land throughout the world. Salinity commonly occurs in irrigated soils because of accumulations of soluble salts in soil profiles over extended periods introduced with the irrigation water. Many dry land soils contain excess salts supplied by the soil parent material and concentrated by water movement. The injurious effects of salts are normally caused more by a limiting of the availability of soil water to plants than by direct toxic effects. Under highly saline conditions the osmotic concentrations of the soil solution may be so high that plants suffer for lack of water on soils that actually seem to have an ample moisture supply.

Irrigation water always contains salts that will be deposited in the soil when the water is evaporated or used by plants. Irrigation intervals and methods must be manipulated to compensate for the reduced ability of salt-affected plants to utilize moisture. Management of the salt balance is required to maintain high crop production rates. Management includes application of excessive irrigation water for leaching excess salts, providing soil drainage, and using proper agronomic practices such as growing salt tolerant crops. These requirements are seldom met, so the worldwide soil salinity problem can be expected to worsen. It must be realized that management of salts cannot be separated from management of water tables which is handled in another section of this report. However, management practices for both are not incompatible and can be conveniently handled, providing they are considered as a common problem.

A salinity problem not associated with irrigation faces a vast agricultural area in the Northern Great Plains and an adjacent area in Southern Canada. The permeable soils of the area are underlain by an

impermeable layer of salt-laden shales. During fallow seasons, and during periods of high rainfall, excess water moves to the salty impervious substrata, picking up salt and gradually moving downslope. This transport of saline water leads to an accumulation of salt in low areas. The salt accumulations are called saline seeps and are affecting a potential area of about 590,000 square km in the U.S. The saline seep problem has accelerated in recent years because moisture conservation practices have increased the available soil water to the point where there is now an excess available to move downslope in some cases. Early identification of these saline seep source areas can lead to corrective measures such as planting salt-tolerant alfalfa to use excess water before it causes the saline seep problem.

17. Effects of Salts

The principal direct effects of water that carry excessive salts are the effects upon the concentration of the soil solution and effects upon the composition of the dissolved and absorbed constituents. The principal indirect effects are the resulting decreased absorption of water by plant roots as the concentration of the soil solution increases, and, to a lesser degree, the specific response of plants to the toxicity of some constituents. Gausman (1975) gives an excellent discussion on the physiological effects on plants of saline soil solutions.

Continued application of saline water to soils may markedly alter soil characteristics and the plants that grow on them. Abandonment of formerly productive soils in many areas around the world has resulted from continued use of irrigation waters with high or moderate quantities of dissolved salts. Thus the ability to determine and monitor the effects of salts on soils and plants is of great importance to agriculture.

Lands which become waterlogged and/or salt-affected are frequently planted to forage crops including grasses. Often, however, forage produced is much lower in yield and quality than could be produced with improved plant species and improved soil-management practices.

Many soils located on lands fed by irrigation projects may acquire accumulations of salts within the rooting profile, with no evidence of their occurrence appearing on the soil surface. Where salts occur, salinity detection is made by using indicator plants where the wide range of salinity effects among crops is understood. The pattern of detectable salinity and

the indicated severity may be influenced by the crops grown. Barley, cotton, and sugar beets are very salt tolerant. Most other cereal and forage crops are moderately salt tolerant. Fruit crops are salt sensitive.

Many times soluble salts are carried to the soil surface by high water tables and by capillary rise above these water tables. When this happens, evaporation results in deposition of salts on or near the soil surface. However, with average soil and crop conditions, the rise of salts to the soil surface can be largely prevented if the water table is kept below a depth of about 0.75 - 1.0 m. Then, of course, some soil leaching may be necessary where the quality of the irrigation water is unfavorable.

At present, detection of saline problems is handled on a piecemeal basis, and only when salinity problems are recognized. By then the application of routine corrective measures is too late. The greatest problem occurs where entire fields may be nearly uniformly affected by salinity in which cases farmers may not recognize the reason for the reduction in yield they may be experiencing.

18. Detection of Stress Conditions

Plants are frequently good indicators of conditions that occur below the soil surface. The root systems of plants explore a rather large soil volume so that plant canopies are more representative of the site conditions than is the soil surface. Many crops growing in saline areas exhibit marked visual symptoms of moisture stress. Salinity may influence leaf color, physiological structure, leaf thickness, pigmentation, hydration, and transpiration. These factors, in turn, can affect the spectral and thermal properties of plants.

Ektachrome infra-red film has been used in applications of photo-interpretation in estimating the severity and extent of known salt-affected areas in cotton fields on non-irrigated farms in the lower Rio Grande Valley of Texas. This film, one layer of which is sensitive in the near-infra-red wavelengths, emphasizes the infra-red reflectance of healthy green vegetation, which appears bright red or pink on the photographs. Cotton plants affected by salinity appear as darker shades of red and, when seriously affected, very dark. White areas on the photo are accumulations of salt on bare soil surface areas.

19. Water Table Management

In many cases benefits obtained from removing excess water have been very conspicuous and have led to a hundred-fold increase in land values. Yet in other cases the usefulness of such drainage has not always been clearly demonstrated. An excessive lowering of the water table may actually lead to a decrease in crop yield in cases where certain crops utilize non-saline soil water from the capillary fringe above water tables. It is obvious that continuous monitoring such as can be provided by remote sensing is necessary in managing water tables in relation to optimum crop production. Management can provide optimum water table depths and prevent fluctuating to the extent that root systems are damaged.

Remote sensing may provide much of the information necessary for implementing corrective measures in areas needing drainage and for managing fluctuating water tables in areas where drainage is not needed or may not be desirable. On irrigation projects in the Western States having substantial acreages of alfalfa, it may be possible to relate emitted radiances from alfalfa fields to water table depths. It is anticipated that evaluations will be made of dominant problems from spacecraft using broad survey methods and from aircraft using more detailed methods.

G. GLOBAL AND UNIQUE APPLICATIONS

Spatial resolution of the Thematic Mapper (30 m for the MSS reflective bands and 120 m for the thermal IR band) will be adequate for mapping water tables on a general reconnaissance level.

The season in which the missions are scheduled for mapping water tables is an important consideration. If crops are used as indicators of subsurface conditions, the best response can be obtained when the canopy nearly or entirely covers the bare soil surface, and when the root system is developed to a substantial depth. This will generally be in July or August in most northern latitudes. Further research may show that thermal sensing of bare soils may yield additional information done in late spring when water tables are usually lowest.

On the Kansas Bostwick project, thermal IR daytime and nighttime imagery was obtained over corn fields affected by water tables at various

depths. Indicated temperature of corn crop related to water table depth was measured at numerous observation wells. Correlations were highly significant, indicating that evapotranspiration of crops during the peak transpiration period of 2 to 4 p.m. is ideal for measuring plant temperatures in relation to high water tables. The time of 11 a.m. for the overpass projected for the Thematic Mapper, though not ideal, is acceptable. Any earlier time of day such as the 9:30 a.m. time of overpass of Landsat 1 and 2 would be unacceptable because the solar insulation at that sun angle does not normally stress the crop. Also, nighttime thermal imagery is needed for detecting surface temperature anomalies on bare soils that may be related to high water tables.

The more northern latitudes of the U.S. are most favorable for thermal infra-red groundwater monitoring because the substantial annual temperature changes that occur yield a relatively greater annual damping depth (Moore and Myers, 1972).

The relationship of cotton leaf temperature to the salinity of the soil was reported by Mers, et al., 1966. The data indicate that the range in leaf temperature associated with variations in soil salinity from 0.5 to 15 millimhos cm-1 was 2.7°C on one date in early June and 5.4°C on a date in late June.

Reflectance changes in infra-red wavelengths associated with moisture deficit may be the result of changes in the size and shape of cells and intercellular spaces as moisture stress progresses. Salinity, which undoubtedly causes similar plant structural changes, also results in an increase in solute concentration within the cell cytoplasm, which may be associated with reflectance contrasts at wavelengths longer than 1.35 μm. It is possible that spectral band No. 5 (1.55 - 1.75 μm) on the Thematic Mapper may be of particular value for detecting salinity in crops.

The Skylab investigations by Richardson, et al., 1975, in Texas, report that 1.09 to 1.19 μm digital data correlated significantly with the salinity of fallow cropland. Unfortunately, the December date for the Skylab overpass in their investigation did not permit collecting reflectance and emittance data for salt-affected crops since very few crops are growing in the area in December.

1. Space Parameters

In nature, the pattern of salinity can be rather erratic, with saline and non-saline soils being interspersed. Abrupt changes from unaffected to barren soils may occur over a lateral distance of a few meters. However, in many instances, with an encroachment of salts from a gradually rising water table, the lateral gradations in salinity are very subtle. Reductions in yields due to salinity often occur over broad areas, resulting in a relatively uniform depression of yields and perhaps a subtle response in some portion of the electromagnetic spectrum. It is in the latter situations where the Thematic Mapper will be especially useful.

Experience has indicated that remote sensing of plant temperatures is most successful when some physiological moisture stress has developed, especially under high evaporative demand conditions. Hence, differences between salt-affected and healthy crops will be more evident if one delays measurements for a week or more following a soaking rain or irrigation and if the measurements are made around noon or in the early afternoon when incident solar radiation and air temperatures are near their maximal daily values.

The spatial resolution of thermal imagery is poorer than that of photographic imagery. Thus the fine detail in photographic coverage can be used to verify stand conditions resulting from uneven plant emergence; to verify disease, insect damage, or nonuniformity of fertility that would affect stand and plant size; to verify percent ground cover differences due to differences in planting data and species; and to verify other features that could complicate the interpretation of the thermal imagery. For these reasons, simultaneous coverage with reflective bands of the area to be thermally scanned is recommended.

The times for acquiring both reflectance and thermal data are important. This is true to a greater degree for thermal data because phenomena being measured generally influence surface temperatures on a diurnal cycle, as well as on seasonal and annual cycles. Different physical manifestations at the same site may be helpful in measuring a single phenomena such as thermal response from vegetation during the afternoon peak of evapotranspiration and soil temperature measurements before dawn.

Temperature contrasts are frequently subtle and may be influenced by meteorological factors which are frequently changing, yet these very dynamic characteristics create the changing thermal environment necessary for detection in the thermal infra-red band.

The Thematic Mapping Mission will provide repetitive opportunities to obtain thermal data that is not feasible to obtain at present.

Landsat 1 and 2 pass over the same area every 18th day, and with their passes staggered by 9 days, give 9-day coverage in areas where they are both operating. That same frequency of coverage by the Thematic Mapper will be sufficient to monitor changes in vegetative cover as the growing season progresses. Passage over the same position at the same hour of the day each time minimizes illumination variations and other sun angle effects.

2. Data Requirements

Increased data requirements are inevitable in development of future space systems. The data demands for uses involving management of dynamic systems such as fluctuating water tables, evapotranspiration, and changing salinity patterns, will be much greater than in the case of uses demanding only data resulting from single or occasional overpasses.

Much of the data mentioned above will require special handling for a coordinate-rectified data base. Processing will have to take into account such factors as geometrical corrections for sensor aspect angle, scale corrections, and coordinate corrections.

Crucial factors concerning data will be the timeliness of data collection and the speed with which the data is transmitted to the user. A successful operational system must meet these needs. The projected thematic mapping mission criteria for collection and distribution of data are satisfactory for the water management uses described herein. However, for assessing crop canopy emittances for irrigation scheduling (not part of this report), data would need to be available to the user in two or three days.

3. Ground Truth

The main requirement for ground truth for water resources interpretation from Landsat data are observations well placed around the area being evaluated. Depth-to-water-table measurements would serve as calibration data

for initial and continuing checks. A crop inventory of the area would be required, at least to the extent that crops in target fields are identified, if agricultural resources are to be monitored.

Meteorological data that should be available include (1) ambient temperature since an important parameter for correlation and comparison purposes is leaf temperature minus ambient temperature and (2) rainfall. These data are available at many locations.

In making such measurements, one should always make enough on the ground observations to verify that the observed thermal or image pattern is due to salinity and not to topographical undulations (which would cause high areas to suffer moisture stress first, and might result in crops crowning out in low areas), to soil texture or soil series patterns, to variations in management of different fields, or to other causes not apparent from the spectral signatures alone.

Data collection platforms, properly managed to avoid excessive data rates, can pay large dividends by providing continuous calibration data, and other data such as meteorological information directly or indirectly related to the phenomena being measured.

For managing salinity and high water tables, the photointerpretation method of extracting information will initially be required. However, once photointerpretation keys and thermal responses are identified, much of the repetitive data processing can be relegated to the computer which can rapidly calibrate and format the data, make correlations, evaluate trends and perform numerous tasks in the decision-making process.

4. Users

There are great pressures for demonstrated practical applications, and many groups are responding to the needs. According to a study by the Battelle Columbus Laboratories as reported in Parade magazine, the average duration from first conception through development and education to first realization of ten new scientific advances was 19.2 years. That period has been shortened for many remote sensing applications. However, currently operational remote sensing applications are limited in number and other potential applications, though numerous, are often difficult and complex, requiring intensive research and development before they can be applied on a routine basis. Even proven applications that have yielded to research require development and demonstration to make them

routinely useful. This will require continual attention and resources.

Principal users of data relating to water tables and salinity are likely to be Federal and State agencies, conservancy subdistricts, irrigation districts, etc. In some instances individual farmers may use the data, particularly since many farms are presently very large in scope, and must depend on automation because of high labor costs.

5. Cost Benefits

Costs and benefits have been established for only a few uses for satellite data, primarily because many applications have not been fully developed, or experience gained to the point where cost-benefits can be established. However, an example of the value of the NASA-RSI effort is the Pennington County, South Dakota (Frazee, et al., 1974), (Westin, et al., 1974) program whereby planners have been provided with a soil association map, land use and land use potential maps, and other resource maps - information that would not have been otherwise available, using conventional methods for many years to come. These maps were then utilized for various land planning purposes.

Wiegand, et al, 1975, have derived cost-benefit information for salinity Skylab studies in Texas which provide favorable economic background data. The investigators compared aircraft costs with satellite costs and reported that any advantage gained in more accurate saline soil mapping at low aircraft altitudes may be offset by higher cost. Saline soil studies, in their report, indicate that satellite (imager) may provide results as good as aircraft results at lower costs. The Texas studies also showed that for their particular salinity application, MSS Skylab and Landsat digital data resulted in cost savings over use of photointerpretation procedures, as also from Skylab and Landsat.

6. Summary

In retrospect, significant progress has been made in the last ten years in understanding the application of the spectral information that will be aboard the Thematic Mapper to measure resource environments. This report has described some demonstrable results from experimentation and monitoring of resource environments. There is no question that further research and development will produce further improvements in these applications.

H. WORLDWIDE CROP PRODUCTION ESTIMATION

Technology, presently developed and planned to be developed for U.S. use, will have a great effect increasing world food production if it is properly applied. Since the objective on a global basis is to increase food production, proper organization of U.S. applications adopted to foreign conditions will do much to assist that effort.

Increasing global food production has three major parts:

- Identification of food production resources;
- Planning the use of resources including supporting infrastructure (power, roads, etc.);
- Implementing the plan to produce food.

Because of satellite imagery ability to examine a whole country, identification of the most promising food production resources are obvious. Many elements of information to develop the plan are also aided from the satellite imagery. Some of these elements are:

- Selection of soil areas;
- Selection of water sources;
- Clues to soil amendments, fertilizers, drainage, etc., that may be required for production;
- Preliminary surveys for flood control, roads, power transmission, etc., that must be part of the plan.

In implementation of the plan, such things as locating sources of construction gravel, soil amendments, and possibly crude fertilizers, near the development site will be necessary.

Unlike the U.S., the developing countries many times have very little resource information. Therefore, any resource information for development that can come from anticipated 1980 technology will be valuable in developing countries than in the U.S., but no special added instrumentation is needed.

There is progress in achieving a level of scientific and technical know-how sufficient to accomplish the task of estimating the worldwide production of major food crops. The Landsat follow-on system will significantly improve the potential for achieving this goal. Considerable research, however, is still required to operationalize the proper mixes of models which include a variety of types of remotely sensed data coupled with collateral material (including field sampling) to provide the locational, spectral, spatial, temporal and resolution components necessary to accomplish this task. Some of the tasks involved in implementing a global crop production inventory system involve research to:

Address the spatial/locational dimensions of estimating a variety of crops worldwide.

Assess the range of spatial resolutions which could result in more accurate estimates of crops in a variety of geographic environments.

Examine the overall effects of the emission and reflection properties of the wide variety of physical and biological parameters which influence crop type determination accuracies.

Test the validity and probability of acquiring adequate multi-temporal data in a variety of environments.

Improve data gathering, processing, analysis, and dissemination procedures.

Integrate meteorological satellite, Landsat series, and other high resolution imaging systems data with collateral material into crop production models.

It can be appreciated that these tasks go beyond the use of Landsat or Landsat follow-on data as the sole remote sensor input. Indeed, to accomplish the goal, preparation must be made to examine complex mixes of systems with:

. Global and/or regional orbital characteristics.

- Spectral sensitivities from the visible into the microwave.
- A variety of spatial resolutions.
- Coverages designed to maximize the potential of cloud-free data during critical stages in the growing cycle.
- Modeling systems designed to accommodate inputs from a variety of sources at a variety of scales and to produce accurate estimates.
- Data management and dissemination systems capable of supplying the user community with the information required in appropriate formats within specific user time constraints.

To the extent that Landsat follow-on satellites improve the capability to accomplish the above tasks, they will improve spatial and spectral sensitivity, which, coupled with more frequent coverage will significantly upgrade the current global monitoring capabilities. The improvement will allow more adequate depiction of fields and crops over a broader spectrum of the geographic environment. Current Landsat resolution limits ability to discriminate small agricultural plots whose total aggregate production is significant. Landsat follow-on resolutions will enhance discrimination and improve acreage estimation accuracies. Improved spectral sensitivities will increase ability to detect various types of stress. It should be re-emphasized, however, that effectively monitoring food production on a global scale will require a mix of systems, platforms, and information-gathering techniques which go beyond the capabilities of any single system.

Current world population growth, coupled with recent setbacks in agricultural production, emphasize the need to plan for more efficient utilization of available food resources. In the coming decades, national and international agencies responsible for inventorying, assessing, and forecasting worldwide agricultural productivity must improve their methods of data acquisition and dissemination. Foremost is the need to develop and implement reliable data-gathering techniques to provide accurate, timely regional and global forecasts for major agricultural crops. Furthermore, these crop production estimates must be made available to planners and decision makers on a near real-time basis to ensure maximum impact. Remote sensing systems, providing regular, synoptic global

TABLE II-2

AGRICULTURAL APPLICATIONS

Application	State of the Art: Operational	State of the Art: Development	State of the Art: Research	Users*
High Water Tables		X	X	CA, CSD, DD, F, FA, ID, SCS, USBR, BIA
Salinity		X	X	CA, CSD, DD, F, FA, ID, SCS, USBR, BIA
Irrigation Management		X	X	CA, CSD, F, FA, ID, SCS, USBR
Soil Moisture		X	X	CA, CSD, F, FA, ID, BIA
Water Budget		X	X	BIA, CSD, FA, ID, SA, SCS, USBR
Ground Water Development		X	X	CSD, F, ID, SCS, SG, USGS, BIA
Soil Survey--Reconnaissance	X			CA, CSD, F, FA, SA, SCS, USBR, BIA
Seed Germination Requirements		X	X	CA, F, ID, SA
Crop Surveys--Acreage	X	X		CA, F, FA, SA, SRS, BIA
Crop Surveys Yield		X	X	CA, F, FA, SA, SRS, BIA
Range Surveys--Biomass	X	X		CA, F, FA, SA, BIA
Disease and Insects	X	X		CA, F, FA, SA, SRS, USBR, BIA
Land Erosion Potential	X	X		CA, CSD, F, FA, SA, SCS, USBR, BIA
Weed Infestations		X	X	CA, F, SA, BIA
Fertility Needs		X	X	CA, F, FA, SA, SCS, SRS, USBR, BIA

*BIA-U.S. Bureau of Indian Affairs
CA-County Agents
CSD-Conservancy Subdistricts
DD-Drainage Districts
F-Farmers
FA-Other Federal Agencies
ID-Irrigation Districts
SA-State Departments of Agriculture
SCS-Soil Conservation Service
SG-State Geologists
SRS-Statistical Reporting Service
USBR-U.S. Bureau of Reclamation
USGS-U.S. Geological Survey

coverage, can plan an important supporting role in achieving these goals.

The socio-economic and political impacts of increased knowledge of worldwide agricultural production are far-reaching. In the U.S. alone the impact of this type of information would be felt from the President and Congress (as they develop import/export policies) to the consumer (paying for commodities). Table II-3 is a representative list of major corporations and government agencies which could benefit from improved grain crop forecasts. In addition, other organizations such as farmer cooperatives, shipping firms, commodity organizations and marketing firms would also benefit from improved, timely crop production estimates.

World food problems developed with disturbing suddenness in 1972. After several decades of sufficient food, actual surpluses, with stable or declining food prices, large grain stocks, and large amounts of food aid, seemed to indicate an increasing capacity to produce more food more efficiently.

In 1972, however, food prices rose sharply, food shortages developed, food aid shipments declined, and grain stocks fell to dangerously low levels. Fears began to be expressed that the world might be approaching the limit of its capacity to increase food production while population continues to increase. (Walters, 1975; Food Task Force, 1974; FAO, 1974; Economic Research Service, 1974; Harkness, 1975.) The important point which arises out of an examination of articles which deal with this topic is the tremendous need for more information on the state and condition of the global food base.

Past and present research indicate that remote sensing offers considerable potential for supplying much needed information on agricultural production. Thaman provides an excellent review of the agricultual applications of remote sensing covering many aspects related to the production of global crop estimates (1974). In the future remote sensing will play an ever-increasing role in production estimation as modeling techniques are refined and the capabilities of a variety of sensor systems to provide data input to forecast models are increased. Many factors are involved in the estimation of agricultural production. Table II-4 includes some of the factors which must be taken into account in the development of a crop production forecast model. With reference to the complexities

TABLE II-3

A SAMPLE OF MAJOR CORPORATIONS AND GOVERNMENT AGENCIES

INTERESTED IN PRODUCTION ESTIMATES FOR GRAIN CROPS

Name of Company	Country of Incorporation	Involved in Grain Trading	Involved in Oil Seed Crushing	Involved in Poultry & Animal Feed Produ
* Bunge Born	Argentina	X (W)	X (M)	X (M)
* Dreyfus	France	X (W)	-	-
* Cargill Inc.	U.S.A.	X (W)	X (M)	X (M)
* Continental Grain	U.S.A.	X (W)	-	X (M)
* Andre CIE.	Switzerland	X (W)	-	-
Schwartz Grain, Ltd.	England	X (W)	-	-
Becher Grain	Germany	X (M)	-	X (G)
G.I.G.	Germany	X (M)	-	X (G)
Toepfer	Germany	X (M)	-	X (G)
Ferutsi Pagnan	Italy	X (M)	X (I)	-
Unilever	Holland/England	-	X (M)	X (M)
Marubini	Japan	X (M)	-	-
Mitsubishi	Japan	X (M)	-	-
Itoh	Japan	X (M)	-	-
Mitsui	Japan	X (M)	-	-
Ralston Purina	U.S.A.	-	X (U.S.)	X (M)
Anderson Clayton	U.S.A.	-	X (M)	X (M)
Central Soya	U.S.A.	-	X (U.S.)	X (M)
Archer Daniels	U.S.A.	-	X (U.S.)	-
Government Entities				
Canadian Wheat Board	Canada	All exporting countries with control over sales of their exports of grain and protein seeds.		
Australian Wheat Board	Australia			
Argentinian Government	Argentina			
Brazilian Government	Brazil			
South African Government	South Africa			

* These five companies account for perhaps 70% of the worlds' grain trade.

(U.S.) in U.S. only
(M) Multi-country
(W) World wide
(G) Germany only
(I) Italy only

TABLE II-4

EXAMPLES OF IMPORTANT CROP PRODUCTION FORECAST MODEL PARAMETERS
(Relative Ease of Acquisition and Primary Sources of Data)

Location Factors	Relative difficulty of obtaining meaningful data[1]	Primary data sources
Latitude (Photo thermal units important here)	Easy	C[2]
Temperature	Easy	C/M[3]
Precipitation	Easy/moderate	M/C
Topography	Easy/difficult	I/C[4]
Soils	Easy/difficult	I/C
Agricultural Practices	Difficult	C/P
Initial Conditions		
Residual Soil Moisture	Moderate/difficult	M/I-C
Varieties of Crops Used	Difficult	C
Planting dates	Easy/difficult	C/I-M
Seed Quality	Difficult	C
Employment of Fertilizers	Difficult	C/I
Modifiers of Maximum Yield[5]		
Soil Moisture	Moderate/difficult	M/C-I
Potential Evapotranspiration	Moderate/difficult	M
Photo Thermal Units	Easy/difficult	M-C
Disease	Difficult	C-I/M
Insects	Difficult	C-I/M
Weeds	Difficult/easy	C-I
Lodging	Easy/difficult	C-I
Meteorological events (frost, flood, hail, winds, dessication)	Easy/difficult	M/I-C
Agricultural Operations		
cultivating	Easy	I-C-M
planting	Easy/difficult	I-C-M
harvesting	Easy	I-C-M

1 Degree of difficulty listed in this table is subjective. Degree of difficulty will be environmentally modulated and dependent (among other things) on such factors as systems spectral responses, resolutions and the amount of accuracies of available ancillary data.

2 Collateral material

3 Meteorological Data

4 Either high resolution or satellite imagery

5 These factors are significantly state-of-growth dependent.

involved in modeling global agricultural production, it is instructive to read a comment from the Earth Satellite Corporation Booz-Allen, Department of Interior Earth Resource Survey Benefit-Cost Study:

> "Errors in yield forecasting are believed to contribute more to uncertainty in production forecasts than do acreage errors, especially in anomalous years. Monthly updatings of harvestable acreages are presently carried out through the growing season, taking account of acres diverted to other uses, abandoned for economic reasons, selectively harvested, plowed down, subjected to winter kill, and so forth. Portions of this yield uncertainty (and) cannot be resolved with any system (emphasis added) -- it arises from uncertainty in meteorological and other random events in nature yet to occur during the growing season. Only improvements in long-range weather forecasting can assist with the weather-related variability." (1974)

The report goes on to state in essence that more research is required to establish the proper correlations and develop the models to achieve sufficient production forecast accuracies to satisfy benefit-cost criteria.

It can readily be appreciated, then, that the integrated modeling of parameters to form a worldwide crop production forecast system is an extremely complex task. Indeed, to quote from the Manual of Remote Sensing:

> "In developing operational approaches to yield forecasts, too much reliance on comparative photos, correlated ground data, and weather data cannot be expected to produce highly accurate results. In attempting to forecast year to year changes, there will be important factors which cannot be identified except possibly at the end of the harvest, and no measure of the effects on yield will be available. Attempts to evaluate the influences of various factors on yields have not been highly successful in terms of conditions encountered on commercial farms. The additional requirement of precise knowledge of the stage of growth when the crop is affected is important but extremely difficult

to secure in most growing conditions on farms because prior budgeting and planning are crucial in solving such problems. The technique of employing many pieces of collateral information is unlikely to provide little more than rational explanations of observed reflectance phenomena. These, if identified, are unlikely to have a known (measurable) effect on yields. Thus, it seems likely that the technology in remote sensing cannot be expected to be exploited to its fullest extent for crop yields because of the need for long range commitments of resources for much more ground data and better designed studies than have ever been available in the past. The collateral ground information, in itself, would probably be sufficient for forecasting yields for most crops. The areas where yield information is the poorest (but for which resources are generally not available) is at counties, or for small areas, or countries without existing current programs of crop production." (Myers, 1976)

If the above statements are taken to mean that crop production estimates utilizing a mix of information from various sources for large areas cannot or will not produce acceptable production estimates, the statements are far too conservative. If, however, they are taken to mean that putting together the proper mix of systems and data for global production estimation is a complex process requiring much ingenuity and allocation of resources, then they are appropriately cautious. Despite these cautions, it is the opinion of many researchers in the field of agricultural remote sensing that crop production forecasts can be accomplished if proper procedures are developed and followed. Indeed, recent papers by Wigton (1975), and Huddleston and Wigton (1975) have shown one area and way in which remote sensing with Landsat 1 and 2 data can substantially upgrade present USDA crop acreage estimates.

In order to provide a context for understanding the comments made earlier, some of the background research which has brought the present level of understanding needs to be examined. One of the earliest attempts at yield estimation (crop production forecasting involves the ability to estimate the acreage of a given crop plus its yield

per acre) from aerial photography was conducted by Dr. R. N. Colwell at the University of California, Berkeley. Colwell used high resolution, black and white, 1:17,000 scale photography for estimating the production of raisin grapes in the San Joaquin Valley, California (1962, 1963, 1965). Farmers in this area needed to secure frequent, accurate estimates of the progress of their harvest to know whether to pick and dry the grapes for the raisin market or to divert them into wine grape production. Imagery from these flights was processed immediately and the photography interpreted as soon as processing was completed. Estimates of production based on counting raisin trays laid between rows of vines were typically available the day following a flight. Utilizing this technique, existing forecasting procedures were then significantly upgraded. It should be pointed out here that this type of procedure (direct counting of harvest yield components) might prove effective for other crops as well. In some areas maize is shocked, hay is stacked or peanuts are left to dry in fields. This technique, however, would require high resolution, more timely data than currently available or planned from spacecraft platforms to produce acceptable estimates.

Another early attempt at providing crop yield data for specific crops was conducted by Mark Systems (Mark Systems, Inc., 1966). In this study high altitude aerial photography and collateral data showed that the ability to provide yield estimates is closely associated with the ability to identify crop types, and such characteristics as maturity, density, vigor and incidence of disease. With these considerations in mind, techniques were developed for estimating yields of wheat, rice, and sugar cane. These techniques specifically involved the collection and utilization of historical crop-yield data, then subtracting yield reduction factors such as low crop density, disease, and excess salinity (all of which could be detected, identified, and measured on aerial photography) from potential yield. Researchers at Mark Systems indicate in their report of this project, that using the technique outlined above, reliable results were obtained.

As early as 1967, researchers began to suggest that satellite remote sensing could benefit agriculture by providing data for earlier, and in some instances, more accurate crop statistics. (Belcher, et al, 1967; Park, 1967.) Reports of research into crop type identification based

on analysis of satellite imagery began to appear even before the current Landsat series of satellites were launched. (Johnson, et al, 1969; Carnegge, et al, 1971; Tham, et al, 1971.) These reports indicated that within certain limits, crops could be identified in these studies related to:

- The spectral properties of the crops
- The mix of crops grown in a particular region
- Size and shape of fields
- Patterns of individual crop phenologies

With respect to research involving Landsat data, varying degrees of success in making either crop type identification, area identifications and/or yield estimations have been reported. (Erb, 1974; Draeger, et al, 1974; Baumgardner, et al, 1974; Wigton and VonSteen, 1974; Dietrich, et al, 1975.) The results of the recent study by Dietrich, et al (1975), can be considered somewhat typical of these types of studies. Dietrich and his colleagues employed man-machine interactive processing to perform agricultural crop identification and acreage determination analysis of Landsat digital data for two 3 . 13 km midwestern study areas. Crop acreage accuracies as high as 99% were achieved. Techniques employed to achieve this degree of accuracy involved analysis of Landsat digital data MSS bands 5 and 7, at 64 gray level resolution (in some cases 128 level resolution), using first cut signatures refined through histogram trimming. The investigators are careful to point out that these techniques may not be successful in all areas, but their results provide encouraging evidence of the utility of man-machine interactive processing systems for agricultural inventories.

Results of Dietrich et al; investigations were obtained using multispectral analysis only. Many researchers are convinced that the accuracies of agricultural surveys can be significantly improved by combining multispectral and multitemporal input data. Crop calendar parameters should also be employed to provide the inputs necessary to differentiate between crops with similar spectral, but different phenological characteristics.

To summarize, the general conclusions of researchers such as Dietrich et al, illustrate the capability to rapidly extract accurate agricultural survey information from Landsat digital data at a number

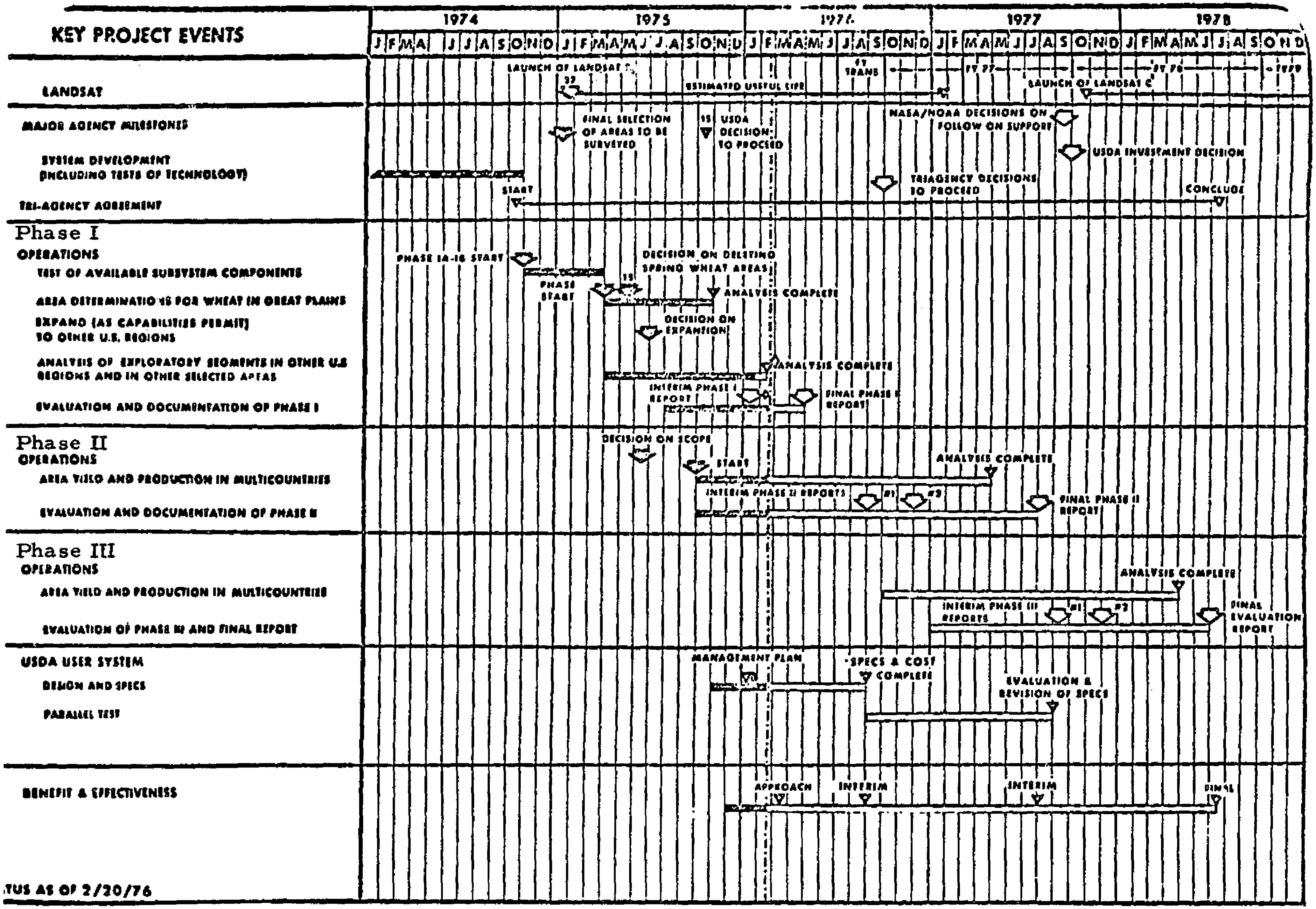
of times during the growing cycle via an interactive data processing system.

Morain and Williams, in their study of wheat production estimation using Landsat image data in Kansas, used a different approach. (1975) Area and production statistics for wheat were derived from satellite image analysis for a 10-county area. The procedure employed in this study involved locating, identifying, and measuring the area of wheat fields on images obtained several times in the growing cycle, and inputting these data into a preexisting yield model. Results (representing the 1972-73 crop year) were compared for accuracy with the SRS August preliminary estimate and final official tabulation. Area estimates from Landsat imagery for dryland and irrigated winter wheat were within 5% of the official figures but predated them by almost one year. Yield on dryland wheat was estimated by the Thompson weather model to within 0.1% of the observed yield. A combined irrigated and dryland wheat production estimate for the 10-county area was completed in July 1973 and was within 1% of the production reported by SRS in February 1974.

It is research results such as those described above which, in part, led NASA, USDA, and NOAA to jointly undertake the LACIE program. LACIE (Large Area Crop Inventory Experiment) is presently concentrating on predicting wheat yields. The program addresses many of the problems involved in providing a worldwide crop production estimate. In this respect LACIE is currently heavily involved in the modeling of many of the parameters listed in Table II-4. Results to date appear encouraging. Table II-5 is a schedule listing the major goals of the project. As can be seen from this table, LACIE is still in an analysis phase and many problems require resolution before a truly global wheat inventory can be operationally initiated. It is significant that a considerable commitment has been made to this program by a number of agencies.

In conclusion, there are strong indications that the state-of-the-art <u>will</u> improve to meet the goal. The Landsat follow-on mission will significantly increase the potential. To achieve this goal, however, not only must sensor systems and the model which goes with them continue to be improved, but increased communication and interaction must occur between remote sensing researchers and users. <u>Appropriate educational programs must be established to implement the transfer of technology to</u>

TABLE II-5



* Courtesy of NASA-LACIE

the user community. Rational, operational, institutional arrangements which provide timely acquisition, processing, analysis, interpretation and dissemination of data to potential users anywhere in the world must also be established. All that has been said herein presupposes that adequate funding is provided for research to advance the state-of-the-art in those areas essential to the development of a global agricultural information system. This system would provide accurate, timely information to a variety of users. At the earliest possible time, operational use of such a system should be demonstrated. Operational implementation should quickly follow. Only then can truly credible and quantifiable benefits be determined.

I. ADJUNCT CONSIDERATIONS

1. Classification Requirements

Classification systems for inventories must meet certain specific standards to be useful. They must be comprehensive, repeatable, and flexible. The classification itself must be comprehensive (in terms of suitable categories); provide a thorough, unique description of each item; and provide for discrete assignment of each item within the inventory.

The most important single consideration requires that the classification system be generated relative to the capabilities and restraints (physical, optical, resolution, scale, etc.) of the sources of information. This controlling consideration is rarely considered, or, at least, adequately explained in the case of uses of remote sensing data. It is particularly abusive where imagery or digital data is presented to the decision maker or user, with completely inadequate legend information such as: red = woods, etc.

The user is given no preparation or opportunity to query "how much" is red, or who or how it was determined what part of the area should be put into red. The technician or operator of the system in use can vary the product with ease. But the most important factors are omitted completely. They are the factors that should be identified and discussed in the definitional sector of a classification system. The parameters should be identified, the identifying characteristics should be listed, the classification description should provide clues to the

significance of the information, and the most frequent or typical situation found in the field or on the ground should be identified.

Classification characteristics and methods, standardized preparation techniques and basic theory and philosophy of classification are areas of weakness recognized by the Applications Survey Group. It will be necessary to resolve this situation soon in order to gain the support of either great numbers of data users for small areas, or smaller numbers of data users for larger areas.

In one instance, the case of the USGS Circular 671 -- "A Land Use Classification System for Use with Remotely Sensed Data", the guidelines mentioned above were adhered to. As a result, it is widely used for a great variety of applications. It is frequently modified for a particular purpose, but was organized to accommodate specific use modifications. Consequently, it is possible to use one data source to meet the needs of many users because the classification system was properly developed.

The capabilities of Landsat follow-on Satellite Program can be related to the U.S.-671 Classification System. The Level I categories will certainly be obtainable from that satellite system. With the recommended changes in resolution (30 meters) and the more favorable frequency of orbits, it is anticipated that most or all of the Level II classification categories of the 671 system will be obtainable from the Landsat follow-on Satellite System.

There is a need to be aware of the existing classification systems when working with remotely sensed data. When there is an opportunity to do so, classification systems should be designed with compatibility as one of the major considerations. To do so creates another degree of applicability for the information being prepared.

In considering the fruitful use of satellite-sensed information, there are a number of ancillary activities that are necessary to varying degrees. A very important one is recognized as the need for a more thorough, philosophical study, and hopefully, research effort on the principles, concepts, and characteristics necessary to develop classification processes and systems relative to the present needs. Only by associating the characteristics of the remote sensors with the classification system used for presenting the information is it possible to

maximize the information retrieval from satellite imagery in a manner that permits its use to the fullest.

2. Information Needs

a. Point of Decision

Other factors must be considered before conclusions about the need for information are firmly established. The kind of information needed is established by the user. And the user is, ultimately, the person who must make a management decision concerning the resource.

In this country, the basic legal powers affecting land and how it is used reside with the states. The states, historically, have delegated these powers to successively lower levels of government (county, town, parish, village, etc.). Residual rights concerning management decisions are subsequently released to the land owners. This direct line of descent of authority to make decisions introduces us to a massive audience of potential users of information concerning land-based resources.

When food and fiber production are considered, our resources of production are influenced by decision makers (consumers of information) at the global, national, state, regional, county, town (or lower unit of government) and individual levels. At all levels more and better information is required to meet the challenges created by changing relationships between population, food, land and energy supplies.

b. Basic Premises

If satellite remote sensing is to be of use to the agricultural sector of our economy, a number of basic premises must be considered, though perhaps not completely understood. The source of an authority to make management decisions concerning agricultural production resides most frequently at the lowest level of the sequence -- the owner. Maximization of the use of remotely sensed information will require reaching that audience for as much of the nation (or world) as possible. Without meeting that goal, successful conversion of satellite acquired data to useful information cannot possibly be realized, and maximum benefits cannot be claimed.

The following are among the points to be considered in determining the kind of format to which remotely sensed information should be reduced for presentation to users.

c. Benefit Sources

Benefits can be claimed only through actions of conversion of the information derived from remote sensing into decision making processes. There are two ways this can occur. One is to reduce the cost of acquisition of data which subsequently must be used for decision making processes. This is a relatively small benefit, but is an important one.

The second source is derived when the use of the information results in better management or increased production of agricultural products. This is the case that leads toward major rewards, and may completely overshadow benefits from reduced cost of data acquisition.

There are no benefits to be claimed from remote sensing data per se. Only through the conversion of the remotely sensed data to information and the use of that information in a management decision can there be an identifiable benefit attributed to remote sensing.

d. Degree of Sophistication

As a general guide line, the higher the level of sophistication, the smaller the numer of agricultural users of remotely acquired data and information. As stated in the introduction, our government process directs the actual management of resources to the lowest level of government and ultimately to the owner of the resource in question. Federal government agencies can and do use information generated through very sophisticated processes. To a lesser extent, state agencies do the same. But as we progress to lower levels, toward the owner/decision maker, there is less ability and/or willingness to be dependent on sophisticated sources of data and information.

In the case of remotely sensed data, we can see that a federal or state agency may have the talent among its personnel to use the information derived through the sophisticated processes. Their decision processes occur over longer periods of time, can be based on macro-statistical and macro-economic concepts, and can usually be of sufficient value when prepared with little or at least less accuracy in terms of geographic referencing.

As we approach the needs of the great number of decision makers, the process of determination is more or less reversed. There is a great need for geographic accuracy, for mapped or graphic output rather than digital data, a far greater need for high frequency retrieval, and less ability to use the process that rely on higher levels of sophistication.

e. Frequency of Need

As a general rule, the lower the level at which management decisions are being considered, the more frequently information is needed. (See Figure II-1.) Consequently, in farm operations the major competition for remotely sensed data is found in the combination of the farmer, his personal experience and his proximity to the physical area of concern. Although farms are getting larger, and some are far too large for personal knowledge to be completely effective, there is as yet no practical way the individual may assess remotely sensed information for the seasonal, short term, or day-to-day management decisions that must be made.

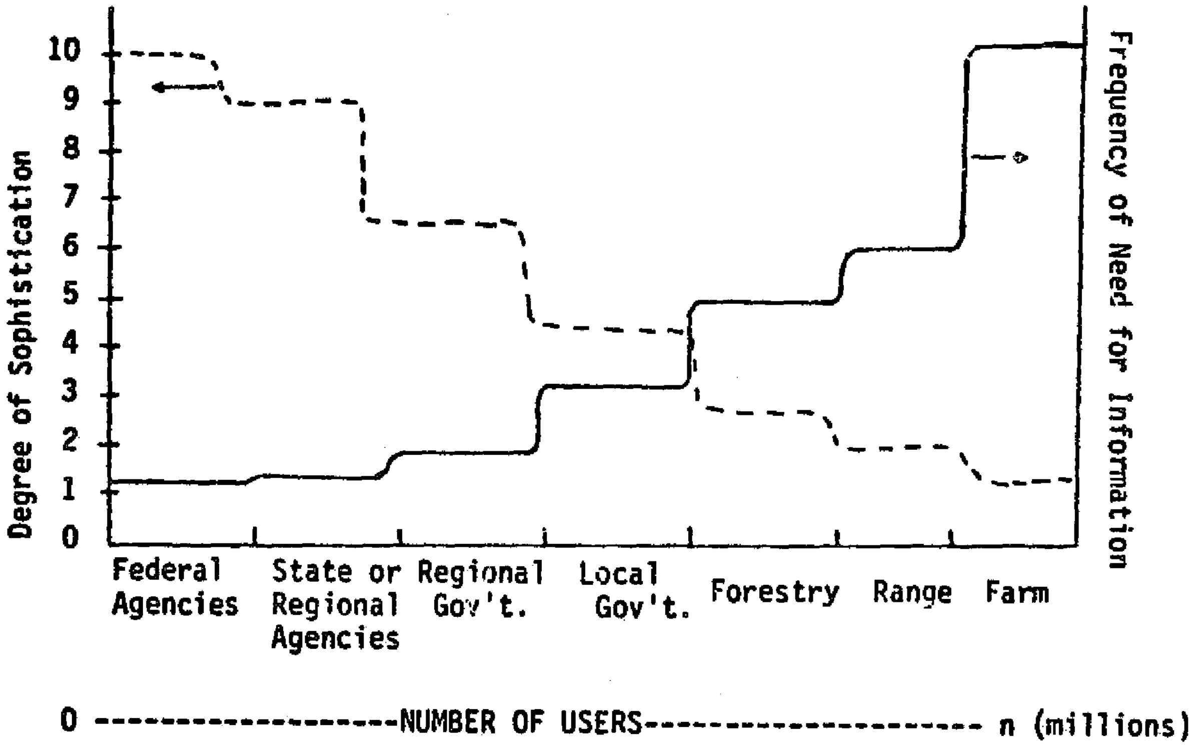
Federal, state and regional agencies rarely make urgent decisions for direct application to resource management. They usually have time enough to wait (except in disaster situations) and more often are concerned about information to use in a documentation process, such as land use change over time. At present, remotely sensed data sources can be used for some of these applications.

f. Simplicity to the User

Government agencies down to the state level usually have access to the talent needed to work with or at least understand information retrieval processes that use such products as CCT output, digital analysis techniques, and the statistical theories necessary for application. This kind of talent is infrequently found at the county level. Counties with major urban centers may have access to this kind of expertise, but in recent surveys on user needs, there are very few professional planning groups that can produce this type of talent resource. Perhaps six counties in New York State could meet this kind of requirement, and perhaps a total of 75 out of the 3,000 throughout the U.S. could do so.

FIGURE II-1

SCHEMATIC REPRESENTATION OF RELATIONSHIPS BETWEEN
SOPHISTICATION OF USER PRODUCTS,
FREQUENCY OF DEMAND,
AND NUMBER OF POTENTIAL USERS



When individual needs below the state level are considered (county, town, private, etc.) there is practically no user audience capable of using the information as it is now prepared. This vast potential audience needs a simplified map or graphic display product that is readily available on a day-to-day basis, acquired locally, at a scale easily recognized, and that presents the information without need for further modification.

g. Growth of User Interest

There is a rapidly generating interest in the potential use of remotely sensed information. Audiences now accept the meteorological data presented daily in newspapers and on TV. They are willing to look at satellite-acquired information, provided it is pertinent to their local area, presents information they can't acquire cheaper elsewhere, and is readily available. Requests are received from user groups below the state level to consider the use of satellite imagery for their needs. To this date, none have actually used it, with the exception of a few demonstrations in research projects.

h. Resolution Factors and Interpretability

High resolution is considered by most of the audience of potential users as being essentially synonymous with interpretability or use. Although this may not be the case, if the potential audience feels it is, we must either accept that as a requirement or undertake a major education effort to prove the case otherwise.

High resolution is in fact necessary for the majority of potential users, especially those who feel they must have graphic display materials to meet their needs, and many users must have that kind of material. Material presented to county planning groups at a ratio of 1:1,000,000 was unimpressive. The same imagery prepared at a scale of 1:250,000 was much more appealing, but still not considered of any use to people at the county level or lower in the management chain. Statistical data presented without geographic referencing was of little interest to these groups.

i. Suitability Related to Large Areas

It is quite obvious that the larger the area (land mass) of concern, the more likely the management group can make use of remotely sensed information. But at the same time, the number of users is reduced, and generally the frequency of demand is lowered. Managers of small areas, such as town and county units, are much more likely to feel that they can see what they want to find out from the ground. And most important, they can do so in a few minutes or hours.

j. Research vs. Operational

It is a major transition to go from the research phase to operational phase. There are two good examples in remote sensing that have made the transition. They are the "fire-scan" operation, and the daily weather satellite reports. These two experiences indicate the kind of problems that must be overcome if satellite remote sensing is to fulfill its promise. There must be a sponsoring agency or group ready to invest in the transition. There must be an audience of users. And there must be a form of interpretation and presentation that requires little or no effort on the part of the final user.

The weather report material from the meteorological satellites meets all the requirements, so well in fact, that many readers of the weather information in the newspapers are no longer conscious of the fact that their weather information was obtained by satellite remote sensing.

Caution must be exercised in stating that something can be done on a performance basis based on the results of research. Applications of remote sensing and meeting the user audience still involve the complex association of the meeting of a Government-sponsored Research and Development program with a user audience. Under the current charter of the R and D organization, there is a major gap to be bridged between the research phase and the operational phase.

k. Summary of the Basic Concepts

There are many favorable points that can be identified.

- The resolution of the imagery can be improved to meet the needs of a much larger audience of users.

- The processing of the imagery can be more rapid.
- There is a growing interest in satellite-acquired information.
- There is a large user audience to be tapped.

But there are a number of other considerations that need attention, and problems that must be resolved.

- There is not yet a large audience of skilled personnel to use the information
- There is no delivery system that provides geographically referenced data at high resolution and high frequency to the general user audience.
- There is no potential for a large number of users of sophisticated products. Aside from federal and state government agencies, there are few possibilities.
- The transition from the research phase to the operational phase has not yet been made.
- Feedback from users is difficult to obtain.

l. Some Needs to be Resolved

Presently, there is a need to convert the research technology to a performance technology for the development of the satellite program. It would be beneficial to look carefully at the elements present in the weather satellite program that have led to its general success: a large audience. Material well prepared. High frequency of coverage. Resolution suited to the users needs. A federal agency ready, willing, and able to take over the operational phase. Rapid turn-around time. A delivery system.

For the most part, the above items are still lacking in the earth resources satellite program. There are a number of items needed, and many of them can be discussed here. The urgency of the situation should not escape attention. The time frame goes to the 1980s, and there is much preparation to be done prior to that date.

m. Classification Standards

It will be necessary to have a much higher level of standardization of classification, properly prepared and documented to meet the needs of

a large user audience. This must include recognition of the variations between and within localities, variable responses to climatic situations, time of day factors, temporal change, and capability at various resolutions. If mass user information is to be prepared, it must be standardized. It can only be standardized through better preparation of the classification process. Much more work needs to be done on classification standards and in preparing classification systems that take the mentioned variables into account.

n. Unique Situations Within the U.S. Department of Agriculture

The USDA has a unique organization structure to facilitate the operational needs of the distribution of satellite information to the user audience. There are direct lines of contact from the federal level to the local county (and town, village and individual level), already established within the USDA. This network of contacts offers the only existing significant delivery system to facilitate distribution of satellite information to the vast audience of potential users on a nation-wide basis.

In addition, the USDA is equipped to train an audience of users to a level satisfactory to understand the utility of satellite-acquired data. The possibility of training the user audience at the county level (or lower) is excellent. No other agency has a comparable capability.

The USDA also has responsibility for a number of important resource inventories that can be used to support or verify satellite-acquired information. Through these activities contacts are already viable with the vast audience desired, and with the audience interested in satellite imagery and its applications.

o. Summary

The conference on prime agricultural lands provided information to justify the need to continue efforts to effectively use satellite-acquired information for resource management.

Much research work has been carried out -- enough to convince many that it is now time to make the transition from a research effort to an operational program. Not all who are involved support this idea.

Although there are many steps that can be taken to favorably influence the use of satellite information, there are many steps needed to meet the requirements and satisfy the basic premises discussed.

Currently, a satisfactory delivery system exists to meet the needs of only a small number of the major users of satellite information. A system has not been obtained which is readily available to the vast audience of users that can provide frequent, accurate, standardized information to the user at his own location, in a format he can use at a time he can use it.

There has been developed a uniquely structured "delivery system" long in use by the USDA, through its system of county and local offices for SCS, ASCS, Cooperative Extension, FHA, etc. And through its great experience and excellent record in maintaining rapport with, and providing services to individual farmers, land owners, and local officials, the USDA appears to have already a currently operational delivery system capable of meeting the urgent needs of the satellite program to reach the major portion of the audience it needs to meet.

J. INFORMATION MANAGEMENT OF SATELLITE-SENSED DATA

1. General

Information management is centered on two points: i.e., the user (market) and the time lapse between sensing and delivery (time frame).

The concern here is not with the quality, cost, or the usefulness of the data acquired by satellite. Quality will depend on future advancements in the mass of technology in remote sensing and analysis, much of which is an unknown quantity today. Cost will depend on the willingness of the Federal Government to support a Landsat follow-on program and absorb all but out-of-pocket costs for data produced. Usefulness will depend on the quality of the data, its relative cost, and the time lapse between sensing and delivery to user.

2. Current Situation -- The Market

The majority of users of currently available satellite data appear to be in the area of geology (mining and petroleum), followed by land management and inland water resources management areas. From the information at hand, it can be estimated that very little data is

currently being used in the areas of forestry, range management and agriculture.

3. Time Frame

The EROS Data Center in Sioux Falls, South Dakota, the distribution center for satellite-sensed data, now receives the data by mail from Goddard Space Flight Center. By the time an order is filled, three to five weeks time may have elapsed since the data was sensed. In some cases it takes much longer. For certain users time is not important, but for potential agricultural uses time is a critical element

For agricultural uses, the data must reach the user community rapidly. Actions to resolve particular problems identified through the use of satellite data must be taken quickly if they can be taken at all. In the future, NASA plans to have data reach the EROS Data Center within 48 hours. This should facilitate getting data to agricultural users much faster than at present.

EROS, however, might consider developing a system whereby interested agricultural users can order data other than by mail order with pre-payment which lengthens the age of the data considerably.

4. Landsat follow-on Program -- The Market

There are two broad groups of users: these are governments and private enterprise. It would appear, particularly in the area of private enterprise, that a large portion of the potential users are not aware of the availability of satellite-sensed data nor how it might be used in their particular cases. Assessed of the data, some companies might have immediate use potential, while others might institute a follow-up program to monitor improvements with an eye towards future use. The same situation may be true with regard to foreign governments and even sectors of the U.S. Government.

An effort should be undertaken to inform the potential user community regarding the technology of satellite sensing, the data availability and the future possibilities for improved data.

5. The Product

Tapes and photographic images should be available from the EROS Data Center in usable form: i.e., radiometrically and geometrically

corrected. In this manner, the data would be ready for rapid introduction into the user's analysis and interpretation system. It has been stated that EROS plans to supply radiometrically and geometrically corrected data in the future.

6. The Cost

Cost of tapes or images purchased from EROS is only a part of the total cost to the user. The value of data will depend on user costs of analysis and interpretation to derive useful information on which management decisions can be made versus cost of other methods to arrive at the same information.

7. Dissemination of Resulting Information

Information derived from satellite data will be handled by companies in the manner which best fits their particular situation.

In governments, however, and primarily the U.S. Government, plans should be developed for the dissemination of information to the lowest level of need. Agricultural departments should see to it that their field services and extension personnel are assessed of area problems and quickly pass the information along to farmers, foresters and cattlemen for remedial action in cases where this is possible.

TABLE II-6
APPLICATION ASSESSMENT TABLE

Application:

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Production Estimates		
Crop recognition. Area determination. Yield models based on reflectance and emittance indicators. Statistical subsampling procedure for verification.	Multispectral and multitemporal recognition of crop. Quantitative estimate of area covered by specific crop by historical climate zones, soils, fertilizer use, and others. Climatological fertilizer consumption, and other data to drive yield models. Reflective estimates of crop growth indicators, e.g., phenological stages, damage by climate, insects, disease moisture deficiency, biomass, management operations, etc.	The crop recognition and mapping in simple landscapes, including limited diversity in crop types, is presently operational. However, where a variety of crops exist, the use of phenology may not be adequate to separate crop types. In such instances considerable ground data and statistical subsampling must occur. The climatological networks, including meteorological satellites already in existence with ground stations are ample in U.S. but limited worldwide. Yield model requires further activity for widescale application. Reflectance and emittance indicators for production are limited but most highly developed in range. The aspects of observing crop diseases, fertilizer deficiencies, insect damage, and other production-degrading parameters are local in nature with limited ability to detect type and quantitative production degradation. Data must applicable to detecting.	The crop recognition is operational in many agricultural regions but does require multi-temporal observations in many instances. Considerable effort will be required for widescale yield prediction or a considerable network of statistical ground samples required. The excellent advantage of management decision-making will have a large impact for disease, insects, etc. However, rapid user procurement of data is required for any application beyond a historical record. Determining "type" of problem is not at all operational except for very local problems but real advantage is.
	Soil Erosion		
Surface roughness, vegetative cover, soil moisture, soil physical proportions.	Vegetation analysis of occurrence and distribution whether growing or surface. Organic debris important for erosion potential. Soil physical properties including soil texture, slope, infiltration capacity, etc., partially available using data as a soil survey tool. Soil moisture associated with thermal inertia.	Erosion potential associated with changes in vegetal cover easily identified. Actual erosion difficult to assess; however, potential erosion areas can be easily identified.	Has small scale applications for large areas. Has special importance in water quality control.
	Bare Soil and Rock vs. Vegetated Areas		
Linear definition between bare soil or rock and vegetative cover.	Very high reflective response, especially on bare soil and rock with crystalline structure. Readily detectable by heat sensing.	Good to excellent.	

TABLE II-6 (Cont'd)
APPLICATION ASSESSMENT TABLE

Application:

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
Macro-linear Identifiers, Timberline (Waterline, Snowline, Desertline)			
Vegetation difference for timberline and desertline. Land mass vs. water in waterline difference. Snowline difference due to temperature, substance and color.	Spectral response occurs in all cases. Thermal response for snow and land-water break.	Good to excellent.	Among the most readily identifiable resource features.
Range and Brushland Interface			
Major difference is between woody-stemmed plant materials and succulent grass and herbaceous growth.	Narrow spectral differences, possibly a textural difference, and in some instances a defoliated period for the woody materials.	Good, generally. These differences currently identifiable.	
Farmsteads			
Consists of buildings, driveways, storage areas, and service areas associated with farm business headquarters.	Must be identified on the basis of shapes, juxtaposition.	Depends on resolution being suitable for identification of building size and shape (poor to fair).	Special types of farmsteads (including grain) would not be identifiable.
Crop Species in Fields One Acre or More in Size (Tree Crops not Included)			
Planting pattern, size, shape, color, season. Need to know if forage intensive or row crop. Soil exposure at full maturity.	Color, tone, configuration, response to exposed soil. Resolution less than 80 m desirable.	Good, provided 30 m resolution is available.	Seasonality must be considered for annual crops. Research needed to standardize spectral response of different crops.
Encroachment -- (a) Desert, (b) Urban, (c) Marginal Production Areas			
Soil, vegetation; land use patterns; soil, vegetation.	Color, density; color, texture, density; color, texture, density.	(a) good; (b) good; (c) good.	(d) Depends on degree.
Monitoring World Agricultural Land Use			
To monitor land currently in agricultural lands. In addition to monitoring present producing areas. Information needs include an assessment of a complex mix of environmental parameters including: soil types, water availability, topography, lithologic materials, natural vegetation, drainage.	Ability to discriminate meaningful land use categories rests on the ability of a sensor to record a variety of interrelated environmental phenomena with respect to Landsat image characteristics which facilitate category discrimination include tone: the various shades of gray which represent a given category of use size: the relative amount of an image which can be classified into a given category. Shape: the general outline of a	Landsat follow-on's increased resolution, improved potential force, multispectral discrimination and greater data quantization and lowered signal-to-noise ratios will definitely improve our capability to discriminate major land use categories.	For a classification to be meaningful at a global scale it should not be so detailed as to swamp a user with data. If continental, national, state, regional, and local land use monitor systems are implemented, they will require progressively more detail data to provide agricultural managers meaningful information upon which decisions can be based.

TABLE II-6 (Cont'd)

APPLICATION ASSESSMENT TABLE

Application:

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Monitoring World Agricultural Land Use (Cont'd)		
	phenomenon can provide clues to its identity. Site: the relative location of a category or class of phenomena with respect to other environmental parameters can aid identification. Association: often certain environmental parameters combine or are grouped to form a single category. Recognition of these types of associations of parameters can facilitate identification of categories. Approximating level two of Geological Survey Circular 671 would provide an adequate international agricultural land use assessment around which a monitoring program could be established.		
	Survey of Irrigation Potential		
Salinity, texture, availability of H_2O, drainage type and density topography.	Encrustation, salt tolerant vegetation. Soil color land form recognition, surface drainage thermal inertia past storm observations. Surface drainage.	See indicators, but need ground truth at reconnaissance level. Also at detailed level to 100 meters or larger gray scale.	Must recognize threshold of detectability. Field inspection recommended.
	Irrigation Scheduling		
Soil moisture status.	(a) Fallow-reflectance emittance.	(a) Fair with longer reflective infrared. A further advantage along with ability to determine thermal inertia. Great potential for economic benefits.	(a) Ability to locate areas of high moisture very promising, but quantification as to content questionable, requiring research and considerable ground data.
	(b) Crop-reflectance emittance.	(b) Reflective indicators have only very local application whereas emittance may provide widespread application. Great potential for economic benefit.	(b) Comparative analysis of surface emittance of similar specied crops may provide information which can be calibrated using known ground conditions.
	Water Budget		
Water Supply. (a) Groundwater; (b) surface water; (c) precipitation. (Covered under separate committee on Inland Waters.)	Water Supply. The climate time and crop phenology to estimate the crop use of water with time.	Water Supply. Identify areas of growing, water-consuming vegetation operation with crop identification in development. These parameters require considerable research.	Water Supply. Applicable to water budgets both domestic and foreign. Considerable potential for establishing new irrigated areas.

TABLE II-6 (Cont'd)
APPLICATION ASSESSMENT TABLE

Application:

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Water Budget (Cont'd)		
Water Demand. (a) Crop surveys; (b) evapotranspiration rates; (c) irrigation presence and efficiency.	Water Demand. Quantitative area determination of crops by species. Use thermal data to determine regions of high evapotranspiration for water loss by working with models for predicting potential ET Survey of irrigated lands using thermal emittance and crop species with geographical context to determine water use and loss with time		
	Water Deficit Areas (Drought)		
Soil moisture; vegetation analysis; surface water occurrences; apparent wind erosion.	Warmer than normal regions. Reflective indicators of vegetation are spatially and temporally erratic and general lack of infrared reflectance. Many salt lakes with normally low infrared reflectance change to dry lakes with salt crust.	Good chances of success with minimum of ground data. Especially application in completely remote areas where ground information is difficult to acquire.	Operational.
	Depth to Water Table		
Locate regions of shallow water tables and predict their depths.	Thermal inertia associated with water-saturated areas. Salt accumulations common on soil surface where water tables are within the capillary fringe. Anomalous cool regions associated with high surface evaporation during dry seasons. Crop damage in cultivated regions. Pheatophytic vegetation anomalous growths. Growth of salt tolerant species commonly an indicator.	Feasible in areas of very shallow water depths where the crop has experienced a considerable damage. Deep water tables only located locally where very specific surface conditions prevail so not a widespread application; however, the problem is widespread and of considerable importance to both dryland and irrigated agriculture.	Requires considerable ground data for obtaining the depth of a quantitative basis. Indicative of occurrence of shallow water regions fairly reliable with local interpreters.
	Water Availability		
Geologic features, chemical analysis, quantity on surface and in wells, depth in wells, recharge.	Water body identification depth, topography.	Surface - good; depth - poor; quality - poor; geology - good; recharge - fair.	Poor penetration, resolution ability, limited.
	Soil Classification		
Geologic materials, soil permeability including subsoil, topography, and plant type.	Color, relief and shadows, vegetation type and amount.	Color - good; relief, shadows - poor; vegetation dependent on resolution, growth stage and continuity.	Resolution limited.

TABLE II-6 (Cont'd)
APPLICATION ASSESSMENT TABLE

Application:

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
	Rangeland		
Quality, variety, grass quantity, topography, soil type, fertility, erosion.	Color, density of vegetation, topography and relief, vegetation type.	Good, good, good, fair.	
	Crop Production		
Type, yield, soil fertility, crop intensity. (Fallow, skip row, double crop.)	Color, color.	Variable, variable.	Dependent on crop stage, stand, planting system. Fallow distinguished from crop, finer delineations difficult.
	Irrigation Potential (Water Supply Assumed)		
Soil type, topography. Crop type, rainfall of area.	Color, relief; color, meteorology.	Variable, good; variable, not applicable.	Vegetation and area; sequential coverage.
	Soil Salinity and Drainage		
Color of soil, permeability, topography, ponding.	Color; relief; color.	Good on large area; good.	
	World-wide Crop Production Forecasting for Major World Food Crops		
Crop type; crop aerial extent; crop vigor; yield potential. Crop type. The ability to differentiate crops of interest from a potentially complex environmental matrix. Crop vigor. Ability to detect a variety of conditions which put stress on a given crop. Aerial extent. The ability to accurately measure the area in a given crop.	Crop type -- general (temporal) phenological information. Crop aerial extent -- spectral information. Crop vigor -- textural information. Yield potential -- spatial information. Crop type. To accomplish crop type determination, we need to have data related to the phenological cycle (crop calendar). Spectral data could also -- specific instance differentiate crops. Texture -- orchard vs. row vs. continuous cover crops. Crop vigor. This to some extent relies on a determination of crop type. Deviations from spectral and spatial norms for a given crop can indicate stress. Aerial extent. Yield potential is related to the ability to determine a crop's types, measure its aerial extents and determine its vigor. To the extent that	Crop type. Improved phenology data can be achieved through earlier signature detection related to greater quantization of data and lower signal/noise ratio. Improvements. Spectral bands can offer improved multispectral differentiation of relatively mature crops. Improved texture may aid in the differentiation of a variety of crops. Certain orchard crops may potentially be detected as a distinct category; however, identification will require ancillary information. Crop vigor. Will facilitate detection of smaller stress areas. Areas down to approximately 1/2 acre. Spectral bands and improved quantization will enhance our ability to detect a variety of stress conditions	This subapplication requires the complex modeling of a variety of environmental parameters. Data needed to accomplish this modeling includes, but is not limited to, meteorological satellite data, aircraft data, field sampling data, and other collateral information. Crop type. (See section on crop type determination.) Crop vigor. (See section on determination of crop stress.) Aerial extent. (See section on crop yields.)

TABLE II-6 (Cont'd)
APPLICATION ASSESSMENT TABLE

Application:

Information Needs (ground features to locate and evaluate)	Parameters (kinds of evidence in imagery, for "information needs")	Feasibility (how capable is Landsat follow-on, of detecting and evaluating the "parameters"?)	Remarks (evidence experience problems, etc.)
World-wide Crop Production Forecasting for Major World Food Crops (Cont'd)			
	the above can be adequately accomplished, there will be potential.	Aerial extent. Landsat follow-on will improve our ability to accomplish this task through improved spectral, spatial, temporal information, and relates to our ability to detect crop type vigor and aerial extent.	
Crop Stage			
(1) Emergence; (2) Pre-flower (pretassel); (3) Flowering; (4) Petal drop (heading); (5) Maturity.	(1) Color, density; (2) color, density; (3) color, density; (4) color, density, (5) color, density.	(1) Poor; (2) Fair; (3) Fair; (4) Poor; (5) Variable to good. Aerial extent to be coupled with ground based statistical samples.	(1) Too similar to follow; (2) Depends on crop and field size; (3) Depends on crop and field size; (4) too little contrast; (5) Good contrast between growing and mature stage for some crops but very difficult to tell harvested from non-harvested in barley, e.g., even though generally easy for alfalfa, e.g., spatial in determining location and extent.
Crop Stress			
Identify locations, types, and aerial extents of stress associated with insects, diseases, moisture, climate, and others.	The comparative advantages of synoptic coverage of reflectance and emittance anomalies to compare stress and non-stress conditions. Multitemporal development of reflectance as an indication. Requires very accurate registration of the data.	The recognition and estimation of aerial extents is feasible. The 9-day proposed repetitive coverage is not adequate except for historical record but normally not adequate for management decisions. The 30 m resolution is not adequate normally for very local applications. The determination of stress type is not feasible at this time.	This application is one which may have the greatest potential application for the local producer.
Brushland, Timberland, Grassland Interfaces			
Succulent herbaceous material succeeding to short woody-stemmed plant material (brush, unmanaged or at maximum growth). Brushland-timberland differences based on height, ground cover, density, percentage of ground cover.	Grassland has very distinct spectral response. Color (seasonally variable). Texture (applicable to forest).	Delineation between grassland-timberland is very good, between brushland and timber generally good, depending on season and regional differences.	Much of this work has already been done with satellite imagery.

CHAPTER III

NOAA LANDSAT DATA REQUIREMENTS

What are the present (NOAA) tasks being done?

Crop modeling and general assessment of weather impact on crops.

Locating crop-threatening weather anomalies.

Techniques being used? Data being used?

Teletype surface reports, weather satellite photos, surface and upper air charts, CLIMAT reports (monthly weather data), USDA reports, State Department reports, newspaper reports.

Where do the presently available remote sensing parameters become restrictive?

Insufficient data for rainfall measurement.

Insufficient data for soil moisture.

No snow-depth capability.

Insufficient temperature resolution.

What remote sensing parameters are needed?

Rainfall.

Soil Moisture.

Snow-Depth.

Temperature ($\pm 1^{\circ}$ C).

Desired?

Radiation.

Crop Growth Stage.

What improvements in the performance of these tasks would result if the parameters just listed were available?

Possibly, a marked improvement in determining crop yields and potential crop problems related to weather.

How will the new data be used? Why are they necessary?

Used as input into crop yield models and used to determine areas of anomalous weather. Lack of current available information over the entire world makes these parameters important.

To what extent will the proposed Landsat follow-on parameters provide the data needed?

Qualitative information on needed parameters will be provided, but lack of quantitative information precludes its consideration in development of statistical crop/climate models.

What auxiliary data will be needed? How critical?

Sensing parameters already listed are needed. For rainfall estimates, would need frequent cloud data. Several photos/day are needed for rainfall estimates.

Improvements over Landsat?

More frequent coverage and more resolution represent an improvement, but more timely and frequent data needed.

Additional research needed to optimally use the Landsat follow-on data? Effects of lack thereof?

Until such time as Landsat can provide quantitative climatological input to the precision needed, in a timely and cost-effective manner, its use to the Center for Climatic and Environmental Assessment (CCEA) will be limited to a contributory, subservient role.

CHAPTER IV

CONCLUSIONS

The Agricultural Applications Survey Group recognizes the growing worldwide demand for U. S. agricultural products. As world population continues to increase, demand for food must increase accordingly; and U. S. agricultural production will be increasingly called on to support foreign as well as domestic food needs.

The value of the U. S. agricultural production justifies continued efforts to improve information acquisition systems, from both conventional and remote sources. Gross farm income has shown consistent increases to $101.5 billion in 1976. Exports (mainly in the area of edible grains) have increased from about $12 billion in 1973 to over $20 billion in 1974, and have remained at that level or above since then. With increased interests in grain purchases, especially in the Eastern European market, it is expected these demands in the market will continue.

Remote sensing capabilities provided by the Landsat follow-on satellite program will provide information of value in managing vegetative crop production. The 1975 value of agricultural products that depend on vegetative production was in excess of $74 billion (this includes livestock production). An improvement of 1 percent, either by increased production or by reduced costs of production, would prove to be worthwhile.

There are multiple time frames associated with the many agricultural uses of remotely sensed data. Demands for information by the great number of users at the production decision-making level are frequent, and must be timely. These management personnel require coverage as often as practical, and the flow of data to these users must not be hampered by a slow turn-around time. Information degradation is extremely rapid for the great majority of this group of users.

To a lesser degree, products for use by decision-makers can make a contribution if obtained on a seasonal or annual basis, but the total benefits that could accrue to remote sensing information would be less. The needs of Federal and State agency users, far fewer in number, could generally be satisfied by the seasonal or annual product, if acquired at times appropriate to specific needs.

Production applications, within one growing season, are best served by instrumentation that detects stress in the plant materials being analyzed. Therefore, stress detection, whether from water abundance or shortage, fertilizer imbalance, insect damage, disease problems, or natural hazards, such as floods or frost, is a major component of the applications in agriculture that will produce rewards. Basically, stress detection calls for bands that will respond to the physical condition of the plant. In addition, it calls for a cross-over time that will record the stress condition. Most stress conditions are much more pronounced during the heat of the day than in the morning or late evening. Therefore, a mid-day crossover time is of major importance to the agricultural users of the data.

There is a need for frequent coverage. On a worldwide basis, there are growing seasons in progress at all times. There is little benefit to be gained, acquiring information for production decision-makers, on a cycle of 18 days or more. The production process simply finds little use for that kind of data/information acquisition cycle where plant stress is the main component of the information source. Consequently, a 9-day cycle, with very little "turn-around" time allowed for data processing and dissemination, appears to be the minimum that would allow benefits to be derived through the management sector of crop production in agriculture. The Agricultural Applications Survey Group does realize that less frequent coverage would be of value to information users concerned with monitoring crop production, changes in land use, etc. And that in many parts of the world data acquisition could be decreased during seasons of plant dormancy or snow cover.

Substantial urgency is required in the planning for a continuous flow of data. There is little use in training a major community of users if gaps are allowed to occur in the flow of data through the system. Conventional data acquisition systems will have to continue, and many will need to be used even after the satellite data system is a fully operational. It is evident, however, that the user will not adopt a totally new procedure, and few can be expected to even modify existing data collection procedures to accommodate Landsat-type data until there is a guarantee that satellite data sources will be continued.

In retrospect, significant progress has been made in the last ten years in understanding the application of the spectral information to measure resource environments. This spectral information will be provided by the Thematic Mapper. There is no question that further research and development will produce further improvements in these applications.

Other Desired Capabilities

In addition to the capabilities of the Landsat follow-on system which the group evaluated, many additional capabilities are technologically feasible. Group members developed a list of important capabilities which should be considered for future satellite systems in the Landsat follow-on series. These capabilities were evaluated in a manner similar to that which the group applied to the other Landsat sensor parameters.

As a result of the discussions by the survey group, the following evaluation received a "consensus" of approval.

Scale: 0 = No opinion
1 = Desirable
2 = Very desirable
3 = Most desirable

Resolution - better than 30 m	3
Additional Spectral Bands	3
Passive Microwave	1
Radar	3
Laser Topog. Profile	1
Fraunhoffer Line Discrim.	2
2.0 - 2.5 μm (with 1.1 - 1.6 μm)	1
8.2 - 9.4 μm (with 10 - 12 μm)	1
Different Variable Time of Day	
Very low sun angle	-
Night (for thermal IR)	1
Non-Sun synchronous	-
Day + Night IR (Max T)	1
Stereo Coverage - complete w/vert. exag.	0

One major consideration discussed at length was the inclusion of high resolution instrumentation (scanners). The survey group very strongly recommends a very high resolution system (similar to the high resolution pointable imager) be included in the Landsat follow-on sensor package as soon as possible. This system would be used in conjunction with the more synoptic equipment to provide a standard, constant sample of high resolution imagery within each pass pattern. This will greatly increase the suitability of the data for analysis through sample design techniques, and will meet the needs of a number of the basic agricultural requirements. This is especially true concerning land use/land cover data that can be analyzed and adequately presented from statistically accepted sample designs and for disaster or unique phenomena applications.

A dedicated Ag-Sat should be considered. Specialized thematic mapping systems would be greatly desired. In addition, work must be promoted on development of low-cost and rapid data processing and disseminating techniques. Geometrically referenced imagery, acquired for a variety of temporal situations, is needed to provide the opportunity for interrelating a variety of data from different hours of passover, and points in time within a phenological sequence.

If Landsat follow-on is to be a practical tool for detecting crop stress, it must: provide imagery to users within two weeks but preferably two days or less of date of imaging; have as good resolution as the Skylab S 190B camera; be used in conjunction with supplemental information; provide data (imagery, etc.) at a reasonable price; and be employed by interpreters familiar with intricacies of modern agriculture.

Landsat data are useful and effective as ancillary input to ground truth in assessment of climatological parameters. The timeliness and qualitative nature of the data, however, preclude its consideration in development of statistical crop/climate models. Until such time as Landsat can provide quantitative climatological input, to the precision needed, in a timely and cost effective manner, its use to the Center for Climatic and Environmental Assessment (CCEA) will be limited to a contributory, subservient role.

The conference on prime agricultural lands provided information to justify the need to continue efforts to effectively use satellite acquired information for resource management.

Much research work has been carried out, enough to convince many that it is now time to make the transition from a research effort to an operational program. Not all involved, however, support this idea.

Although there are many steps that can be taken to favorably influence the use of satellite information, there are many steps needed to meet the requirements and satisfy the basic premises discussed.

Currently, a satisfactory delivery system exists to meet the needs of only a small number of the major users. A system has not been produced that is readily available to the vast audience of users that can provide frequent, accurate, standardized information to the user at his own location, in a format he can use at a time he can use it. It should reach the local level frequently, provide geographically referenced output, be available at low cost, with suitable resolution, in a format that needs no further interpretation.

There has been developed a uniquely structured "delivery system" long in use by the USDA, through its system of county and local offices for SCS, ASCS, Cooperative Extension, FHA, etc. Through its great experience and excellent record in maintaining rapport with, and providing services to individual farmers, landowners, and local officials, the USDA appears to have the only currently operational delivery system capable of meeting the urgent needs of the satellite program to reach the major portion of the audience it needs to meet.

One can envision a system operated on a nationwide basis, through county contacts that would retrieve on demand the most recent available information for that locality concerning that particular area about any activity, or resource condition, as requested by the user.

Present systems of data analysis are not yet capable of preparation of data to these standards. Work must continue toward this end if the goals of maximizing the benefits to be derived from remote sensing are to be met.

In conclusion, there are strong indications that the state-of-the-art for interpreting remotely sensed data in agriculture will provide the operational capabilities desired. The Landsat follow-on mission will significantly increase potential for this achievement. To achieve this goal, however, not only must sensor systems and the model which goes with them continue to be improved, but increased communication and interaction

must occur between remote sensing researchers and users. Appropriate educational programs must be established to implement the transfer of technology to the user community. Rational, operational, institutional arrangements which provide timely acquisition, processing, analysis, interpretation and dissemination of data to potential users anywhere in the world must also be established. All that has been said herein presupposes that adequate funding is provided for research to advance the state-of-the-art in those areas essential to the development of a global agricultural information system. This system would provide accurate, timely information to a variety of users. At the earliest possible time, operational use of such a system should be demonstrated. Operational implementation should quickly follow. Only then can truly credible and quantifiable benefits be determined.

CHAPTER V

RECOMMENDATIONS

The Applications Survey Group for Agriculture, upon reviewing the working papers prepared for the study sessions, and after lengthy discussions, has reached a consensus but not a unanimous decision, to submit the following recommendations.

A. OPERATIONAL CONSIDERATIONS

* The development of the "follow-on" satellite system on the schedule presented is anticipated.

* The proposed 9-day cycle is essential if growing season production management decisions are to be made based on satellite acquired data.

* The higher resolution proposed for all the data in the follow-on series is desired and should be provided.

* A mid-day cross-over time is extremely important to agricultural users, as the best rewards for production applications will come from detection of stress conditions which are not pronounced enough for accurate recognition at an earlier hour.

* A turn-around time of no more than 48 hours must be achieved if the data is to approach maximum use to the majority of users.

* Spectral regions should be directly associated with the application.

* Information should be prepared based on an increased number of shades of gray.

* Geographical registration of the products should be improved.

* Thermal imagery should be acquired both night and day when requested.

* A high resolution scanner should be used in conjunction with synoptic equipment to provide a constant, standard sample within the pass frame. (This would be the only data required for many applications.)

* The data form for users should include graphic geographically referenced display as well as statistical output.

B. RECOMMENDATIONS FOR RESEARCH

* Low-cost rapid data processing techniques need to be developed.
* Efficient dissemination systems need to be developed immediately.
* Development of a coordinate, rectified data base is recommended.
* A serious review of computer efficiency must be undertaken, especially in view of the predicted state-of-the-art by 1980.
* Classification theories should be rigorously studied and definitional concepts compatible with remote sensing products thoroughly explored and documented.
* Work should be initiated to address the spatial/locational dimensions of estimating a variety of crops worldwide.
* The overall effects of the emission and reflection properties of the wide variety of physical and biological parameters which influence crop type accuracies should be examined.
* The validity and probability of acquiring adequate multi-temporal data in a variety of environments should be tested.
* Integrate meteorological satellites, Landsat series, and other high resolution imaging systems data with collateral material into crop production and resource management models.
* Attention must be given to the development of processes and systems that allow for dissemination to the largest logical audience of users in the various formats of their choosing.

C. RECOMMENDATIONS FOR MANAGEMENT

* Formalize the Agricultural Applications Survey Group as a standing committee dedicated to maximizing the user input to the NASA decision-making process as applied to agricultural applications of remote sensing. The Committee should have co-representation from USDA, USDI, NOAA, and advisory units or personnel from NASA. In addition to the members who worked on this report, there should be representation from the banking community, the transportation and marketing groups, from plant physiology, plant genetics, and from the public policy interests. The committee should not exceed

20 members, and rotation of membership could be provided if it appears desirable.

* Better coordination between groups within the remote sensing community should be promoted, especially between Government, University, and Industry.

* Efforts should be made to recognize the present shortcomings of the relations with the potential audience of users. At the user level it often appears that overselling has had a damaging influence and that there is:
  - Too much emphasis on expensive equipment
  - Too little emphasis on applied remote sensing techniques
  - A shortage of skilled interpreters;
  - A paucity of remote sensing data on crop stress conditions in large field commercial setting rather than on control or test plots;
  - And, finally, too few people know about the existence of the data.

* Recognize the significance of the satellite information source to developing countries. It may be the only source of national data.

* Recognize the need to have the imagery interpreted by interpreters familiar with the intricacies of modern agriculture.

* More attention should be given the user audience that will have to depend on some form of manual interpretation, or at best, a combination of manual and mechanized methods.

* Educational programs, of a general nature, should be undertaken to familiarize a larger audience of potential users with the potential of satellite-acquired information. This need only be adult audiences. The various service organizations, high school, science groups, 4-H, Scouts, etc., should be approached in this program. Today's high school freshmen will be eligible to vote before the Landsat follow-on satellite program is underway. It would help if they knew enough about NASA activities to be favorably inclined toward the various NASA programs.

* Consider development of cooperative assignments with existing agency systems already prepared to disseminate information to large audiences at the local level.

* Global applications need increased immediate consideration, especially in view of population increases, decreasing land resources, and increased demand for food.

* Recognize the continued need for supplemental data (satellite data will not provide all our information), and put some effort into determining what is useful, how valuable it might be, and how valuable it would be if combined with satellite data.

* The large audience of users should be recognized. Maximum benefits from remote sensing can only be realized when the decision-maker is reached with the information. That person is usually the owner of the resource. Therefore, serious consideration on how best to meet his needs should guide many of the research activities of the (agricultural) applications program.

* Finally, and most important, preliminary planning should be started for the development of an Ag-Satellite to be programmed for the mid-1980's.

APPENDIX A

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APPENDIX B

ACRONYMS

ASCS	Agriculture Stabilization and Conservation Service
ASG	Applications Survey Group
CCEA	Center for Climatic and Environmental Assessment (NOAA)
CCT	Computer Compatible Tape
DCP	Data Collection Platform
EROS	Earth Resources Observation Satellite
FHA	Federal Housing Administration
GRSU	Geographical Remote Sensing Unit (University of California at Santa Barbara)
GTS	Global Telecommunications System
GOES	Geostationary Operational Environmental Satellite
IR	Infrared
JPL	Jet Propulsion Laboratory
LACIE	Large Area Crop Inventory Experiment
L-1	Landsat 1
L-2	Landsat 2
L-C	Landsat C
L-Fo	Landsat follow-on
MSS	Multi-Spectral Scanner
NASA	National Aeronautics and Space Administration
NESS	National Environmental Satellite System
NOAA	National Oceanic and Atmospheric Administration
RSI	Remote Sensing Institute
SCS	Soil Conservation Service
S190A	Skylab Experiment Designations
S190B	Skylab Experiment Designations
TM	Thematic Mapper
USDA	U. S. Department of Agriculture
USDI	U. S. Department of Interior
USGS	U. S. Geological Survey
VISSR	Visible Infrared Spin Scan Radiometer
WMO	World Meteorological Organization

APPENDIX C

RESUMES

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Dr. Frederick P. Weber, Remote Sensing Coordinator, U.S. Forest Service, Resources Evaluation Staff, was recently appointed manager of the new nationwide Forestry Application Program for the Forest Service at the Lyndon B. Johnson Space Center, Houston, Texas.

In his former position, Dr. Weber supervised Forest Service research projects in advanced remote sensing technology at the Special Mapping Center in Reston, Virginia. He also served to coordinate remote sensing programs nationwide. In his new assignment Weber is responsible to the Forest Service and NASA for the management of the Cooperative National Program in forestry and range applications of remote sensing.